

# *Subcontractor Report*

## **Renewable Energy and Energy Efficiency Technologies in Residential Building Codes**

**June 15, 1998 to September 15, 1998**

D. Wortman and L. Echo-Hawk  
*Wortman Engineering*  
*Boulder, Colorado*



# **NREL**

**National Renewable Energy Laboratory**  
1617 Cole Boulevard, Golden, Colorado 80401-3393  
303-275-3000 • [www.nrel.gov](http://www.nrel.gov)

Operated for the U.S. Department of Energy  
Office of Energy Efficiency and Renewable Energy  
by Midwest Research Institute • Battelle

Contract No. DE-AC36-99-GO10337

# **Renewable Energy and Energy Efficiency Technologies in Residential Building Codes**

**June 15, 1998 to September 15, 1998**

D. Wortman and L. Echo-Hawk  
*Wortman Engineering*  
*Boulder, Colorado*

NREL Technical Monitor: S. Hayter

Prepared under Subcontract No. AAA-8-18450-01



# **NREL**

**National Renewable Energy Laboratory**  
1617 Cole Boulevard, Golden, Colorado 80401-3393  
303-275-3000 • [www.nrel.gov](http://www.nrel.gov)

Operated for the U.S. Department of Energy  
Office of Energy Efficiency and Renewable Energy  
by Midwest Research Institute • Battelle

Contract No. DE-AC36-99-GO10337

## NOTICE

This report was prepared as an account of work sponsored by an agency of the United States government. Neither the United States government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States government or any agency thereof.

Available electronically at <http://www.osti.gov/bridge>

Available for a processing fee to U.S. Department of Energy  
and its contractors, in paper, from:

U.S. Department of Energy  
Office of Scientific and Technical Information  
P.O. Box 62  
Oak Ridge, TN 37831-0062  
phone: 865.576.8401  
fax: 865.576.5728  
email: <mailto:reports@adonis.osti.gov>

Available for sale to the public, in paper, from:

U.S. Department of Commerce  
National Technical Information Service  
5285 Port Royal Road  
Springfield, VA 22161  
phone: 800.553.6847  
fax: 703.605.6900  
email: [orders@ntis.fedworld.gov](mailto:orders@ntis.fedworld.gov)  
online ordering: <http://www.ntis.gov/ordering.htm>



## Executive Summary

This report is an attempt to describe the building code requirements and impediments to the application of EE and RE technologies in residential buildings.

Several modern model building codes were reviewed. These are representative of the codes that will be adopted by most locations in the coming years. The codes reviewed for this report include:

- International Residential Code, First Draft, April 1998
- International Energy Conservation Code, 1998
- International Mechanical Code, 1998
- International Plumbing Code, 1997
- International Fuel Gas Code, 1997
- National Electrical Code, 1996.

These codes were reviewed as to their application to (1) PV systems in buildings and building-integrated PV systems and (2) active solar domestic hot water and space-heating systems.

A discussion of general code issues that impact these technologies is also included. Examples of this are solar access and sustainability.

The relationships of the technologies to the codes are discussed with two major issues in mind:

- How do the codes treat these technologies as building components?
- Do the codes allow reasonable credit for the energy impacts of the technologies?

There are issues with the codes in both regards, with many examples given in the report. As such, recommendations are given for four types of future action to make the codes reviewed in this report more accommodating to RE technologies. These recommendations include the following:

1. Include the suggested language additions and changes listed in Appendix C of this report in the codes.
2. Create new code sections that place all of the requirements for a technology in one section of an appropriate code. This would include language-specific technology, as well as references to other applicable code sections.
3. As appropriate, apply existing standards to innovative RE and energy efficiency technologies. An obvious example of this is the application of the existing standards for asphalt shingles to PV shingle products. If the existing standards are applicable, code language should be amended to specifically refer the standard to the technology.
4. Develop new standards, as necessary, to ease code compliance. Again, code language would need to be amended to specifically refer the new standard to the technology.

A synergy may be possible in developing suitable code language changes for PV and solar hot water systems. The installation of rooftop PV panels and solar hot water collectors involve many overlapping issues. Roof loading, weather tightness, mounting systems, roof penetrations, and similar concerns are identical for both technologies. If such work can be coordinated, it appears reasonable that organizations supporting both technologies could work together to implement the appropriate revisions and additions to the codes.

## **Preface to the Report**

This report is an attempt to describe the building code requirements and impediments to the application of EE and RE technologies in residential buildings. The goal is to include all relevant issues raised in the codes. However, because of the complex and often confusing language in the codes, this report is not necessarily comprehensive. Also, the authors are generalists in these technology fields and may not have the in-depth knowledge and practical experience of the reviewers in some specific technologies. This report was reviewed by specialists in many of the technologies, with the goal of filling in these areas.

The author thanks Linda Echo-Hawk for help with the writing and review of this report. Sheila Hayter and Ron Judkoff of NREL provided funding and general guidance for the project. In addition, Sheila and Ron reviewed the entire draft report. Dr. Jay Burch of NREL provided input on the section covering active solar domestic hot water and space heating systems. Dick DeBlasio of NREL provided guidance and reviewed the material on PV systems in buildings and building integrated PV systems. Steve Slayzak of NREL reviewed the material on desiccant dehumidification systems. Dr. Chuck Kutscher of NREL reviewed the section on solar-assisted ventilation systems. Toni Smith of NREL reviewed the section on innovative fenestration systems of products.

All opinions in this report are those of the authors.

David Wortman, PE

Linda Echo-Hawk

## Definitions

AC	alternating current
ACH	air changes per hour
AFUE	Annual Fuel Utilization Efficiency
CFM	cubic feet per minute
COP	coefficient of performance
DC	direct current
DHW	domestic hot water
DOE	U.S. Department of Energy
EE	energy efficiency
HSPF	Heating Seasonal Performance Factor
HVAC	heating, ventilation, and air conditioning
IECC	International Energy Conservation Code
IFGC	International Fuel Gas Code
IMC	International Mechanical Code
IPC	International Plumbing Code
IRC	International Residential Code for One- and Two-Family Dwellings
NEC	National Electrical Code
NREL	National Renewable Energy Laboratory
PV	photovoltaic
RE	renewable energy
SEER	Seasonal Energy Efficiency Ratio
SHW	solar hot water
TMY	Typical Meteorological Year

## Table of Contents

Executive Summary .....	iii
Preface to the Report.....	v
1.0 Introduction .....	1
2.0 About this Report .....	3
2.1 Codes and Technologies.....	3
2.2 Scope .....	5
2.3 Comment on Footnotes .....	5
3.0 General Issues of Code Impacts on Renewable Energy and Energy Efficiency Technologies.....	6
3.1 Alternatives to Materials, Design, Methods of Construction and Equipment .....	6
3.2 Solar Access .....	6
3.3 Sustainability .....	7
3.4 Climate Criteria.....	7
3.5 Energy Compliance Paths .....	8
3.6 Inappropriate Prescriptive Requirements in the International Residential Code Performance Path .....	9
3.7 Building Energy Analysis Methods .....	10
3.8 UL or Comparable Listing of Electrical and Mechanical Components.....	11
3.9 Economic Realities .....	11
3.10 Complication and Expense of the Performance Path as a Deterrent to Innovation .....	12
3.11 Requirements for Renewable Energy Sources to Qualify under the IECC Performance Path.....	12
4.0 Code Impacts by Technology .....	14
4.1 Photovoltaic Systems in Buildings and Building-Integrated Photovoltaic Systems .....	14
4.1.1 Photovoltaic Systems and the National Electrical Code .....	14
4.1.2 Photovoltaic Systems and Structural and Mechanical Requirements .....	17
4.1.3 Photovoltaic Systems and Systems Analysis of the IECC .....	24

4.1.4	Summary of Codes and Standards for PV Systems .....	25
4.2	Active Solar Domestic Hot Water and Space-heating Systems.....	26
4.2.1	Active Solar Hot Water Systems and Systems Analysis of the IECC .....	38
4.3	Passive Solar Energy and Low-energy Design .....	40
4.3.1	Glazing Area, Orientation, and Shading .....	40
4.3.2	Thermal Mass .....	43
4.3.3	High Efficiency Equipment, Appliances, and Water Use.....	44
4.3.4	Passive Solar Energy, Low-Energy Design, and Systems Analysis of the IECC .....	46
4.4	Innovative Roof/Attic, Wall, Floor, and Foundation Systems .....	46
4.4.1	General Issues.....	46
4.4.2	Code Implications of High R-Value Components.....	47
4.4.3	Code Implications of High Thermal Mass Components .....	48
4.4.4	Code Implications of Components that Modify Solar Radiation .....	51
4.4.5	Code Implications of Less-Expensive Wall Systems .....	51
4.4.6	Code Implications of Components that Reduce Air Infiltration .....	52
4.4.7	Innovative Roof/Attic, Wall, Floor, and Foundation Systems and Systems Analysis of the IECC.....	52
4.5	Innovative Fenestration Systems or Products .....	65
4.5.1	Innovative Fenestration Systems or Products and Systems Analysis of the IECC .....	66
4.5.2	Sunspaces .....	67
4.6	Innovative Heating, Ventilation and Air Conditioning (HVAC) Systems.....	69
4.6.1	Improved Efficiency .....	70
4.6.2	Equipment with Part-load Curves Tailored to Real World Load Histograms .....	70
4.6.3	Improved Control Strategies, including Smart or Adaptive Controls .....	71
4.6.4	Variable-speed Fans or Pumps .....	71
4.6.5	High-efficiency Motors .....	72
4.6.6	Mechanical Ventilation .....	72

4.6.7	Evaporative Cooling .....	73
4.6.8	Multiple Zoning in Buildings .....	73
4.6.9	Ground-source Heat Pumps .....	73
4.6.10	Gas cooling, including Engine-driven Heat Pumps and Absorption Cooling .....	74
4.6.11	Innovative Heating, Ventilation, and Air Conditioning (HVAC) Systems and Systems Analysis of the IECC .....	74
4.7	Electrical Lighting, Daylighting, and Associated Controls .....	79
4.7.1	Code Implications of High-Efficiency Lamps and Fixtures ..	79
4.7.2	Code Implications of Daylighting Controls and Associated Circuits .....	80
4.7.3	Code Implications of Windows Associated with Daylighting .....	80
4.7.4	Code Implications of Core Daylighting and Light Pipes .....	81
4.7.5	Innovative Electrical Lighting and Daylighting and Systems Analysis of the IECC .....	81
4.8	Innovative Thermal Storage Systems .....	84
4.8.1	General Code Considerations .....	84
4.8.2	Innovative Thermal Storage Systems and Systems Analysis of the IECC .....	85
4.9	Buildings Requiring No Heating and/or Cooling Equipment .....	86
4.9.1	Buildings Requiring No Heating and/or Cooling Equipment and Systems Analysis of the IECC .....	87
4.10	Buildings Requiring No Conventional Air Distribution (Duct) Systems .....	89
4.11	Solar-Assisted Ventilation Systems .....	90
4.11.1	Solar-Assisted Ventilation Systems as Ducts .....	90
4.11.2	Solar-Assisted Ventilation Systems as Solar Collectors .....	91
4.11.3	Solar-Assisted Ventilation Systems as Building Walls .....	91
4.11.4	Solar-Assisted Ventilation Systems and Systems Analysis of the IECC .....	91
4.12	Desiccant Dehumidification Systems .....	93
4.12.1	Desiccant Dehumidification Systems and Systems Analysis of the IECC .....	93

5.0	Appendix A: A Comparison of the SRCC Document OG-300 and the Reviewed Codes in Regards to Active Solar Hot Water .....	95
6.0	Appendix B: ASHRAE Standard 90.2 Energy-Efficient Design of New Low-Rise Residential Buildings and Energy Credit for Renewable Energy and Energy Efficient Technologies .....	100
6.1	Photovoltaic Systems in Buildings and Building-Integrated Photovoltaic Systems .....	101
6.2	Active Solar Domestic Hot Water and Space-Heating Systems ..	101
6.3	Passive Solar and Low-Energy Design .....	101
	6.3.1 Glazing area, orientation, and shading .....	101
	6.3.2 Thermal Mass .....	102
	6.3.3 High-efficiency Equipment, Appliances, and Water Use ...	102
6.4	Innovative Roof/Attic, Wall, Floor, and Foundation Systems .....	102
	6.4.1 Components with High-R-Value.....	102
	6.4.2 Components with High Thermal Mass .....	102
	6.4.3 The Ground as Thermal Mass .....	102
	6.4.4 Components that Modify Solar Radiation .....	102
	6.4.5 Less-expensive Wall Systems .....	102
	6.4.6 Components that Reduce Air infiltration .....	103
6.5	Innovative Fenestration Systems or Products .....	103
6.6	Innovative Heating, Ventilation, and Air Conditioning (HVAC) Systems.....	103
	6.6.1 Higher-efficiency Equipment.....	103
	6.6.2 Equipment with Part-load Curves Tailored to Real-world Load Histograms.....	103
	6.6.3 Improved Control Strategies, including Smart or Adaptive Controls .....	103
	6.6.4 Variable-speed Fans or Pumps .....	104
	6.6.5 High-efficiency Motors .....	104
	6.6.6 Mechanical Ventilation .....	104
	6.6.7 Evaporative Cooling.....	104
	6.6.8 Multiple Zoning in Buildings .....	104
	6.6.9 Ground-source Heat Pumps .....	104

6.6.10	Gas Cooling, including engine-driven Heat Pumps and Absorption Cooling .....	104
6.7	Electrical Lighting, Daylighting, and Associated Controls .....	104
6.8	Innovative Thermal Storage Systems.....	105
6.9	Buildings Requiring No Heating/Cooling Equipment.....	105
6.10	Buildings Requiring No Conventional Air Distribution (Duct) Systems.....	105
6.11	Solar-Assisted Ventilation Systems .....	105
6.12	Desiccant Dehumidification Systems.....	105
7.0	Appendix C: Suggestions for Code Changes .....	108
8.0	Appendix D: Suggestions for Potential Research Areas .....	113
9.0	Appendix E: Tables of Code References, Categorized by Renewable Energy and Energy Efficiency Technology ....	120
10.0	Appendix F: References.....	156

## **List of Tables**

Table 1.	Partial List of Important Articles in the National Electrical Code for PV System Installations .....	15
Table 2.	Summary of Standards and Reviewed Code Sections relevant to PV Systems .....	26
Table 3.	Code References for Photovoltaic Systems in Buildings and Building-Integrated Photovoltaic Systems.....	120
Table 4.	Code References for Active Solar Domestic Hot Water and Space-Heating Systems .....	125
Table 5.	Code References for Active Solar Domestic Hot Water and Space-Heating Systems: Code References for Passive Solar.....	131
Table 6.	Code References for Passive Solar: Innovative Envelope and Foundation Systems .....	135
Table 7.	Code References for Envelope and Fenestration Systems: Innovative Heating, Ventilation, and Air-Conditioning (HVAC) Systems.....	141
Table 8.	Code References for Innovative HVAC Systems: Electrical Lighting, Daylighting, and Associated Controls .....	146
Table 9.	Code References for Electrical Lighting, Daylighting, and Associated Controls: Innovative Thermal Storage Systems .....	149
Table 10.	Code References for Innovative Thermal Storage Systems: Buildings Requiring No Heating/Cooling Equipment.....	152
Table 11.	Code References for Buildings Requiring No Heating and/or Cooling Equipment: Buildings Requiring No Conventional Air Distribution (Duct) Systems .....	153
Table 12.	Code References for Buildings Requiring No Conventional Air-Distribution Systems: Solar-Assisted Ventilation Systems.....	154
Table 13.	Code References for Solar-Assisted Ventilation Systems: Desiccant Dehumidification Systems .....	155

## 1.0 Introduction

Widespread acceptance and market penetration of energy efficiency (EE) and renewable energy (RE) technologies in buildings depends on compliance with existing and proposed building codes. Practitioners must understand the possibilities and constraints provided by the codes before they can legally install these technologies. The codes generally apply to both new construction and modifications to existing buildings.

The various building codes were not developed to promote EE but to safeguard the public. Industry, research, standards and other interested organizations participated in their development. An example is the “International Residential Code For One- and Two-Family Dwellings” (IRC<sup>1</sup>). Publication of the IRC in final form is planned for the year 2000 and is designed to potentially be the basis for many of the legally acceptable building codes in the United States. The IRC references other codes, such as the “International Energy Conservation Code” (IECC)<sup>2</sup>, the International Mechanical Code (IMC)<sup>3</sup>, and so forth, for rules regarding special technical areas. The purpose of the IRC is to “provide minimum requirements to safeguard life or limb, health and public welfare and affordability.”<sup>4</sup> Although this includes “affordability,” this is not an evident priority in most of the various codes. Indeed, only the IECC has any reference to EE in its intent or purpose section. Reinforcing the main goal of building codes, the IECC “is not intended to abridge safety, health or environmental requirements under other applicable codes or ordinances.”<sup>5</sup> There is no explicit discussion in the IECC or any other Code as to “affordability” or economic feasibility in their application.

Building codes have been in use for a long time. However, the “energy crisis” of the 1970s produced a flood of new building-related EE and RE technologies, equipment, and construction techniques. The development of many of these innovations came from outside the traditional construction industry and without the normal scrutiny of applicable standards organizations. The installation of many such systems did not meet the requirements of the existing building codes. A large number of these systems, particularly active solar heating and domestic hot water systems, produced disappointing performance and reliability as well as other problems.

Research and product development on EE and RE technologies has proceeded in the two decades since the energy crises of the 1970s. The development of sophisticated technologies has occurred through the application of a lot of bright ideas, the pursuit of economically optimized designs, and the weeding out of bad ideas. The EE and RE technologies often rival or exceed the sophistication of more traditional technologies. Some of these innovative technologies are cost-effective today. Many more would become instantly cost-effective if a 1970s-style increase in energy prices and the uncertain availability of energy supplies should revisit this country. However, even under those circumstances, compliance to building codes can present a major obstacle to significant market penetration. In order to make a major impact on energy use in this country, EE and RE technologies need acceptance by all the different interest groups involved in the construction process. Financial interests will not likely finance what they perceive as risky technologies because of Code compliance issues. Construction companies will not likely train workers for what they perceive as markets that are limited by the building codes. Moreover, in a chicken-and-egg fashion, manufacturers of these

technologies often do not have a large enough market to justify the expense of UL or other standards type testing required for compliance.

Local Code officials are ultimately responsible for the health, safety, and reliability of the buildings in their jurisdiction.<sup>6</sup> They can approve non-standard equipment, designs, materials, and so forth that are outside of the explicit scope of existing building codes. However, acceptance must satisfy typical building Code language such as “the material, method or work offered is, for the purpose intended, at least the equivalent of that prescribed in this Code.”<sup>7</sup> Further, if the technologies do not meet the existing approvals, “the Code official shall have the authority to require tests as evidence of compliance . . . . Test methods shall be as specified in this Code or by other recognized test standards.”<sup>8</sup> The Code officials are less likely to approve unconventional approaches if they cannot rely on generally recognized codes or standards. This represents a large obstacle to their acceptance of these technologies.

A path around this obstacle is to include language in the codes that specifically addresses the issues involved with EE and RE technologies. In lieu of this, documentation, including standards-based testing, of how interpretations of the existing codes allow the application of these technologies, can also be used to convince local officials of their acceptability. Inserting appropriate language in the codes and standards and providing this documentation must necessarily be an activity of the EE and RE industry and supporting research organizations. The ready acceptance of these technologies by local officials will ease their acceptance by the other interest groups needed for their widespread implementation.

This report addresses these issues. Various codes are reviewed, with reference to their impacts on photovoltaic and solar thermal technologies. Barriers to implementation of these technologies are noted and discussed. Alternative Code language, necessary testing, documentation, and other strategies for acceptance are also presented.

---

<sup>1</sup> International Code Council, Inc. April, 1998. International Residential Code for One- and Two-Family Dwellings, First Draft. International Code Council, Inc.

<sup>2</sup> International Code Council, Inc. March, 1998. International Energy Conservation Code, 1998. International Code Council, Inc.

<sup>3</sup> International Code Council, Inc. January, 1998. International Mechanical Code, 1998. International Code Council, Inc.

<sup>4</sup> IRC, 101.3 Purpose

<sup>5</sup> IECC, 101.2 Intent

<sup>6</sup> IRC 104.1 “The code official is hereby authorized and directed to enforce the provisions of this code.”

<sup>7</sup> IRC, 104.11 Alternative materials, design and methods of construction and equipment. Equivalent language is in all of the various codes.

<sup>8</sup> IRC, 104.11.1 Tests

## 2.0 About this Report

### 2.1 Codes and Technologies

As stated in the Introduction to this report, the IRC may become the basis for many of the building codes in the United States after it is released in the year 2000. The IRC references other codes that will also likely become applicable at that time. The reviewed codes included in this report are as follows:

- International Residential Code, First Draft, April 1998<sup>9</sup> (IRC)
- International Energy Conservation Code, 1998<sup>10</sup> (IECC)
- International Mechanical Code, 1998<sup>11</sup> (IMC)
- International Plumbing Code, 1997<sup>12</sup> (IPC)
- International Fuel Gas Code, 1997<sup>13</sup> (IFGC)
- National Electrical Code, 1996<sup>14</sup> (NEC)

These codes were selected for this report because they are representative of the latest generation of the available model building codes. Widely used model building codes in the United State are published by several other organizations. Model codes have no legal authority in a jurisdiction until they are put into force through enabling legislation.

Two proposed Code sections are also reviewed for this report:

- Article 690 of the NEC 1999: Solar Photovoltaic Systems.<sup>15</sup> This is intended to be included in the 1999 NEC.
- SRCC Document OG-300: Solar Water Heating Systems.<sup>16</sup>

Technologies considered in this report include the following:

- **Photovoltaic Systems (PV) in Buildings and Building Integrated Photovoltaic Systems.** The PV systems can be stand-alone, hybrid, or utility-connected. These systems can be mounted on the building roofs or walls, integrated as roof or wall components, or ground mounted. The relevant codes include the NEC, the structural sections of the IRC, and the RE sections of the IECC.
- **Active Solar Domestic Hot Water (DHW) and Space-Heating Systems.** The active solar hot water systems can be roof, wall, or ground-mounted. The relevant codes include the IPC, the Solar Systems and structural sections of the IRC, the Solar Systems section of the IMC, and the control signal and circuit language in the NEC.
- **Passive Solar and Low-Energy Design.** This involved energy efficiency, solar-oriented glazing, and thermal mass. The relevant codes include the energy analysis and other sections of the IECC.
- **Innovative Roof/Attic, Wall, Floor, and Foundation Systems.** Relevant codes include the insulation sections of the IRC and the IECC and the structural sections of the IRC.

- **Innovative Fenestration Systems or Products.** Relevant codes include the window sections of the IRC and IECC.
- **Innovative Heating, Ventilation, and Air-Conditioning (HVAC) Systems.** A wide range of potential innovations is possible in HVAC systems, including the adaptation of commercial system technologies to residential applications. These include mechanical ventilation and economizers; variable-speed fans, pumps, and compressors; adaptive controls; and others. The relevant codes include the IMC and the energy analysis and other sections of the IECC.
- **Electrical Lighting, Daylighting, and Associated Controls.** This includes local and core daylighting systems, as well as light pipe technologies. The relevant codes include sections of the NEC, structural- and firestop-related sections of the IRC, and the energy analysis section of the IECC.
- **Innovative Thermal Storage Systems.** These can store either heating or cooling in water, ice, phase-change, or other media. The relevant codes include the IMC, some sections of the IPC, and the energy-analysis sections of the IECC.
- **Buildings Requiring No Heating / Cooling Equipment.** These buildings can maintain adequate comfort conditions without relying on heating and /or cooling equipment. The relevant codes include the energy analysis sections of the IECC and Section 303.6 of the IRC.
- **Buildings Requiring No Conventional Air-Distribution (Duct) Systems.** These include buildings with hydronic cooling systems, as well as ductless heating or cooling distribution. The relevant codes include sections of the IPC and IMC.
- **Solar-Assisted Ventilation Systems.** Transpired solar collectors are used to pre-heat building ventilation air. Relevant codes include the IMC, the wall and window sections of the IRC, and the energy-analysis sections of the IECC.
- **Desiccant Dehumidification Systems.** These use desiccant materials to reduce the humidity in the ventilation or supply air. The moisture is removed from the desiccant (regenerated) by heat from fuel, electric, or renewable sources. The relevant codes include the IMC and the energy-analysis sections of the IECC.

Specific code sections that impact these technologies are noted by footnotes in the following discussion of each technology.

In addition, other issues and Code sections impact a range of EE and RE technologies. This includes, for example, the lack of discussion of solar access, whether from other buildings shading of the subject building or the subject building's shading of other property. These general issues will also be addressed.

The relationships of all of the technologies to the codes are discussed with two major issues in mind:

- First, how do the codes treat these technologies as building components? This includes both the obvious Code sections, as well as those that are more obscure. An example of the former is that the electrical components of PV systems must be designed and installed to comply with the requirements of the NEC. An example of

the latter is that roof-mounted PV systems can also be considered roof structural components and coverings and must, therefore, comply with the structural sections of the IRC.

- Second, do the IECC and other codes allow reasonable credit for the energy impacts of the technologies? This concerns two issues: Is credit allowed, and are the methods used to quantify the energy savings in the codes practical to apply and reasonable and fair to the technologies?

The codes can impact the implementation of these technologies in several ways. These include the following:

- The technology is not mentioned in the codes. The view in this report is that this situation is an obstacle to implementation of the technology. The solution is to develop appropriate explicit sections or language in the codes.
- The technology is discussed by the codes, but the language is confusing or ambiguous. The solution here is to clear up the language.
- The technology is discussed in the codes, but the discussion is spread over several sections or different codes. The problem is that practitioners may not easily find all of the relevant material that should be considered. The solution here is to put all relevant information in one section, or to more clearly reference relevant sections.
- The technology is prohibited by the Code. Examples of this were not found. However, energy credit for some technologies cannot be achieved with the requirements of these codes.

The codes almost entirely ignore the economic issues related to the building technologies. Investments in energy-related technologies are reasonably based on economic criteria. For example, the building component minimum required U-values in the IECC are based only on the heating degree days for the location. This ignores the heating fuel and electricity costs and other utility-rate structure details. Electrically heated houses, with much higher effective heating fuel rates, are required to have the same level of insulation as natural-gas-heated houses in the same location. Detailed economic discussions are outside the scope of this report.

## **2.2 Scope**

This report covers the application of the codes listed above to residential buildings with one- and two-dwelling units. While some of this discussion may apply to other building types and other RE and energy efficiency technologies, these are not specifically addressed here.

## **2.3 Comment on Footnotes**

To reduce the length of this report, abbreviations for the various codes are generally used throughout the section endnotes in this report. The full references are available in Appendix F.

### **3.0 General Issues of Code Impacts on Renewable Energy and Energy Efficiency Technologies**

Some sections of the various codes apply to many of the technologies. There are also areas of concern that are not addressed by any of the codes. These are discussed in this section.

#### **3.1 Alternatives to Materials, Design, Methods of Construction, and Equipment**

Language in all of the codes allows alternatives that are not explicitly covered by the letter of the codes. The intent is to allow practitioners the flexibility to introduce new approaches to solving the classic problem of designing and constructing safe, comfortable buildings. For example, a section of the IRC states, “The provisions of this code are not intended to prevent the installation of any material or to prohibit any design or method of construction not specifically prescribed by this code. . . .”<sup>17</sup> However, these alternatives shall only “be approved where the code official finds that the proposed design is satisfactory and complies with the intent of the provisions of this code, and that the material, method or work offered is, for the purpose intended, at least the equivalent of that prescribed in this code.”<sup>18</sup> If there is insufficient information for the code official to determine if the proposed complies with the intent of the codes, then “the code official shall have the authority to require tests as evidence of compliance to be made at no expense to the jurisdiction. Test methods shall be as specified in this code or by other recognized test standards.”<sup>19</sup>

This represents opportunities for both the introduction of innovative building technologies and an economic obstacle to their market penetration. On the one hand, any innovative technology could be legally used in a building if a local code official allows it. However, convincing individual code officials of the acceptability of a technology is likely an expensive and slow process, making it an impractical approach to the widespread implementation of the technology in many localities. The remedy to this problem is to conclusively show compliance with the existing codes, if possible. To show compliance, pertinent sections of the codes must be examined and, if necessary, the new technology tested to the relevant standards. If the existing standards are not appropriate for the new technology, then the practitioner, supplier, trade organization, or other entity should be prepared to provide for the development of such standards. If the existing codes are not appropriate for showing compliance for new technologies, then these same entities should be prepared to develop and implement appropriate sections of future versions of the codes that address the new technologies. These are likely slow and expensive processes. Suggested code language changes and standards needed to ease the compliance for each of the following technologies are included in this report.

#### **3.2 Solar Access**

Solar access is the ability of a solar energy system to “see” the sun. The codes reviewed for this report did not address solar access issues. It is likely outside the scope of the codes to regulate activities on adjacent properties or public areas that impact the solar

access for a solar energy system. However, it seems appropriate to include language to require that these should be considered at the time of the installation. Shading from structures, topography, trees, and so forth need to be considered in the energy analysis sections of the IECC. Shading from objects on the same property where the solar system is installed also needs to be addressed. While it is unlikely that they can control activities on other properties that could shade the solar system, local officials likely have the jurisdiction to prevent the system owner from construction or planting activities that limit the system's solar access.

Language can be added to the IECC to account for the potential impact of solar access from shading objects or trees located on other properties and from permanent or future objects, including trees, on the subject property. It is reasonable to expect energy contributions of the solar system to be calculated under the worst case solar access conditions. Sample language could be included in IECC 402.1.3.11, a subsection of "Input values for residential buildings."

**402.1.3.11 Solar access.** Any existing permanent objects which will reduce the solar gains on any window surfaces or other solar energy collection devices, must be accounted for in the energy analysis.

Similar language should also be included in Code sections on active solar systems and PV solar systems.

### **3.3 Sustainability**

Sustainability encompasses the concepts of energy efficiency, RE utilization, minimal use of other resources, and minimal or positive environmental impacts. Generally, the issues of "minimal use of other resources, and minimal or positive environmental impacts" are ignored in the various codes. One aspect of the sustainable building industry is to use recycled materials. This is explicitly covered in IRC section 104.9.1: "Used materials, equipment and devices shall not be reused unless approved by the code official." Recycled materials should not be used unless the code officials are previously informed of their use and have agreed to it.

Environmental impacts, including air pollution from on-site fuel burning and off-site electric generation and greenhouse gas production are not discussed in the codes. These concerns are not considered by code officials when EE and RE technologies are considered.

### **3.4 Climate Criteria**

Design weather conditions and appropriate long-term climate data are controversial and dynamic. The choice of these data impacts both the design criteria for building component and HVAC equipment as well as annual energy analysis. A major concern is the impact of global warming. Is global warming actually changing the climate? If it is, what is the impact for each building code jurisdiction? The Typical Meteorological Year (TMY)<sup>20</sup> hourly weather data sets are widely used to drive building energy simulation programs. The original TMY data presents an annual data set designed to represent

typical weather and is derived from data collected from 1951 through 1990. Recently the TMY data sets were updated with the release of the TMY2<sup>21</sup> data sets. These are derived using measured weather data from the years 1961 through 1990. The intent is to account for climate changes, presumably the result of global warming, between the two time periods.

The performance path through the IRC is the required compliance method for all RE technologies and the likely method used for innovative EE technologies.<sup>22</sup> This chapter requires the use of an hourly building energy simulation tool.<sup>23</sup> The requirement for climate data used to drive this tool is “Coincident hourly data for temperatures, solar radiation, wind and humidity of typical days in the year representing seasonal variation.”<sup>24</sup>

There is no specification on the source or validity of this data. A more constraining specification would increase the consistency of the performance path results and likely increase the accuracy of these results. However, it is not always possible to obtain such data for all locations. Therefore, the best available and appropriate credible weather data source should be used for the performance path analysis.

### **3.5 Energy Compliance Paths**

Compliance with the IECC and similar energy codes is designed to ensure that buildings do not exceed a maximum permitted level of annual energy use. These codes have two general types of approaches to determine compliance. The prescriptive path defines minimum energy-related requirements on a component-by-component basis. These can be opaque or glazed surfaces, air-sealing packages, portions of mechanical systems, and similar components that affect the energy usage. The codes generally allow trade-offs that let one component fall short of compliance if another compensates for it by exceeding the minimum requirements. The advantage of the prescriptive path is that it is easy to understand and inexpensive and simple to apply. Its disadvantages include the inability to account for a range of technologies. The prescriptive path to compliance is generally accurately applicable to

- some low-energy designs;
- most innovative roof/attic, wall, floor, and foundation systems;
- most innovative fenestration systems or products;
- some innovative heating, ventilation and air conditioning (HVAC) systems.

The alternative to the prescriptive path is the performance path. This requires modeling of the building and its mechanical systems, to determine the annual energy usage. Two buildings are modeled: a standard design that meets the minimum prescriptive path requirements and the proposed building design. The codes specify the allowed differences between the two designs. The advantage of this path is that accurate models can provide a more-accurate evaluation of the proposed design than the prescriptive requirements. In addition, sufficiently detailed simulation models can analyze almost any type of EE and RE technology. However, such analysis can be very expensive, particularly if done correctly. This can be a major obstacle to pursuing this compliance

path, which is a deterrent to code compliance of the technologies that require it. The performance path is generally required to accurately analyze the following technologies:

- Photovoltaic systems in buildings and building-integrated PV systems
- Active solar domestic hot water and space-heating systems
- Some passive solar and low-energy designs
- Some innovative heating, ventilation, and air-conditioning (HVAC) systems
- Electrical lighting, daylighting, and associated controls
- Innovative thermal storage systems
- Buildings requiring no heating/cooling equipment
- Buildings requiring no conventional air distribution (duct) systems
- Solar-assisted ventilation systems
- Desiccant dehumidification systems.

### **3.6 Inappropriate Prescriptive Requirements in the International Residential Code Performance Path**

The scope statement of the IRC performance path states that “This chapter establishes design criteria in terms of total energy use by a residential building, including all of its systems.”<sup>25</sup> Language in the chapter contradicts this statement by requiring specific design features without consideration for their energy impacts. Such requirements may be appropriate for prescriptive path compliance, but they should be eliminated from the IECC performance path. These requirements include the following:

- “Passive solar building designs shall provide documentation, acceptable to the building official, that fixed external or other acceptable shading is provided to limit excessive summer cooling energy gains to the building interior.”<sup>26</sup> This both contradicts the scope statement and is too loosely worded to be consistently interpreted or enforced. There is no explicit definition of “passive solar” in any of the reviewed codes, so it is not clear which designs to apply this requirement. There is also no definition for “excessive summer cooling energy gains.” Because the goal of the performance path is to limit total annual energy use, this requirement for shading — which reduces cooling loads, but likely increases heating loads — unnecessarily restricts potential designs.
- “Passive solar buildings shall utilize at least 45 Btu/°F of additional thermal mass, per square foot of added glass area, when added south-facing glass area exceeds 33 percent of the total glass area in walls.”<sup>27</sup> This prescriptive requirement also unnecessarily restricts potential designs.
- The maximum number of zones that are allowed for the performance path analysis is two.<sup>28</sup> One method of reducing the energy use in buildings is to include an HVAC system that can heat and/or cool multiple building zones simultaneously. This permits separate zones to be conditioned with a minimum amount of energy and

prevents HVAC over-heating or over-cooling of different building areas. Zones that are used for only portions of the day can then have different setpoints and setpoint schedules. This prescriptive language in the IECC prevents designers from taking credit for these types of systems and strategies. Other requirements in this section of code are similarly restrictive.<sup>29</sup> These limit the heating and cooling setpoints, and the maximum setback/set-up temperature differences, duration, and number per day.

### **3.7 Building Energy Analysis Methods**

The requirements for the allowed simulation tools used to perform the analysis in the IECC Chapter 4 (the performance path) are specified in the IECC Section 402.3.2. It states:

The calculation procedure used to simulate the operation of the building and its service systems through a full-year operating period shall be detailed to permit the evaluation of the effect of system design, climatic factors, operational characteristics, and mechanical equipment on annual energy usage. Manufacturer's data or comparable field test data shall be used when available in the simulation of systems and equipment. The calculation procedure shall be based upon 8,760 hours of operation of the building and its service systems and shall utilize the design methods specified in the ASHRAE Handbook of Fundamentals . . .

This language is ambiguous and does not necessarily require that a true hourly simulation program be used. There are, for example, bin method simulation programs and "typical day" simulation programs that, although "based upon 8,760 hours of operation," do not capture the true thermal dynamics required to accurately analyze buildings with features like set-back thermostats or significant levels of thermal mass. Both types of programs were developed when computing power was expensive and computers were relatively slow. Many design firms use these methods, possibly because they learned to use them a long time ago. However, these programs will produce inaccurate results for many types of building designs that incorporate EE or RE technologies.

Bin method programs count the hours in each of a series of temperature bins and then typically perform a steady-state heat loss/gain calculation on each bin. The hourly loads are then multiplied by the number of hours in each bin, and these are summed over all the bins to produce annual results. This neglects the coincidence of solar radiation and ambient temperatures and is totally incapable of accounting for building thermal mass effects or the impacts of setback thermostats or other non-linear control strategies.

The "typical day" approach creates typical days out of the annual weather data. The typical days might be weekday and weekend days for each month. These days are simulated, but only 2 days worth of run-time is needed to simulate each month. This saves a significant amount of computer run-time, but again neglects many of the thermal details that are of particular interest to the EE and RE design community. This approach misses the extreme weather conditions each month and cannot account, for example, for the Tuesday morning start-up loads after a 3-day weekend. These nuances are not likely to be noticed by the typical local code official. Accordingly, language similar to the following should be included in the IECC.

#### **402.3.2.1 Special requirements for appropriate energy analysis tools.**

If the proposed design involves significant amounts of thermal mass, contains thermal control systems with non-linear control characteristics, then a true 8,760-hour annual simulation driven by appropriate weather data shall be used in the systems analysis.

**402.3.2.2 Hourly simulation tools for photovoltaic system analysis.** If the proposed design involves a PV system to generate electricity, then a true 8,760-hour annual simulation driven by appropriate weather data shall be used in the systems analysis. This simulation shall be capable of analyzing the type of PV system specified in the design. This analysis shall use the hourly electrical loads from the building simulation as the basis for the analysis of the PV system.

In addition, an exception allows residential buildings with less than 5000 ft<sup>2</sup> of floor area from requiring the hourly simulation analysis. However, “comparison of energy consumption using correlation methods based on full-year hourly simulation analysis or other engineering methods that are capable of estimating the annual heating, cooling, and hot water use between the proposed alternative design and the standard shall be provided.”<sup>30</sup> The simplifying assumptions inherent in all correlation methods limit their accuracy and flexibility in analyzing real-world building designs. This is a tradeoff between the cost of performing the energy analysis and the accuracy and applicability of the results.

### **3.8 UL or Comparable Listing of Electrical and Mechanical Components**

Electrical “conductors and equipment required by this Code [the NEC] shall be acceptable only if approved.”<sup>31</sup> “Approval” is defined as acceptable to the authority having jurisdiction.<sup>32</sup> Components of mechanical systems have similar requirements. “All appliances and equipment installed in mechanical systems covered by this code shall be listed and bear the label of an approved agency or shall be approved by the building officials for safe use.”<sup>33</sup> In practice, these requirements are satisfied if the electrical and mechanical equipment has been tested and is labeled by Underwriter’s Laboratory or a similar testing organization. Local code officials are not likely to approve their use if such certification is missing.

### **3.9 Economic Realities**

Economic conditions vary greatly at different locations. Electric utility rate structures, fuel costs, heating fuel availability, utility and government incentive programs, and other factors can all have a primary impact on appropriate building design. Such considerations, as well as the cost of alternative energy design approaches, should be the driving factor in selecting envelope and mechanical systems as well as EE and RE technologies. Many houses built in the 1970s have electric heating because no gas taps were available when they were built. It seems reasonable that electrically heated houses could be built to a higher level of envelope thermal performance than houses with much less expensive natural gas or other fuels. There is no consideration given to heating fuel

costs in any of the codes. An argument can be made that all economic conditions, including utility rate structures, will change in the future, particularly in light of potential utility deregulation. However, this does not appear to be a sufficient reason to ignore these issues in regards to compliance with the building codes.

### **3.10 Complication and Expense of the Performance Path as a Deterrent to Innovation**

The engineering cost to perform the systems analysis of the IECC energy performance path is likely to be at least several thousand dollars for a typical dwelling. People building new houses, especially the custom houses likely to include the EE and RE technologies, will have higher priorities than spending this money on additional engineering and analysis. Proponents of these technologies should develop prescriptive path methods to help implement Code compliance. It is easy to envision this approach for technologies like PV and active solar DHW systems, where the RE performance is relatively independent of the other building details. Available maps, tables, and simple algorithms could be used to show the annual energy performance for each of the various optional designs of such systems. A similar approach could likely be developed for many of the other technologies included in this report. The quantitative impacts of passive solar tempering of conventional building designs, some types of innovative HVAC systems, daylighting, and desiccant dehumidification could likely be dealt with in a similar manner.

### **3.11 Requirements for Renewable Energy Sources to Qualify under the IECC Performance Path**

“To qualify . . . such renewable energy must be derived from a specific collection, storage, and distribution system.”<sup>34</sup> Not all RE systems use all of these components. A PV system with utility connections, but no storage, is one example. Once through active solar hot water systems are another. This language should be removed from the IECC.

---

<sup>9</sup> International Code Council, Inc. April, 1998. International Residential Code for One- and Two-Family Dwellings, First Draft. International Code Council, Inc.

<sup>10</sup> International Code Council, Inc. March, 1998. International Energy Conservation Code, 1998. International Code Council, Inc.

<sup>11</sup> International Code Council, Inc. January, 1998. International Mechanical Code, 1998. International Code Council, Inc.

<sup>12</sup> International Code Council, Inc. April, 1998. International Plumbing Code, 1997. International Code Council, Inc.

<sup>13</sup> International Code Council, Inc. November, 1997. International Fuel Gas Code, 1997. International Code Council, Inc.

<sup>14</sup> National Fire Protection Association. 1995. National Electrical Code. National Fire Protection Association.

<sup>15</sup> Unpublished draft of Article 690 of the National Electrical Code, 1999: Solar Photovoltaic Systems.<sup>15</sup>

---

<sup>16</sup> Solar Rating and Certification Corporation. April, 1997. SRCC Document OG-300 Operating Guidelines and Minimum Standards for Certifying Solar Water Heating Systems: An Optional Solar Water Heating System Certification and Rating Program. Solar Rating and Certification Corporation.

<sup>17</sup> IRC 104.11

<sup>18</sup> *ibid.*

<sup>19</sup> IRC 104.11.1

<sup>20</sup> Balcomb, J.D., 2001

<sup>21</sup> Marion, W. and K. Urban. 1995. User's Manual for TMY2s (Typical Meteorological Years) derived from the 1961-1990 National Solar Radiation Database. NREL/TP-463-7668. National Renewable Energy Laboratory, Golden, CO.

<sup>22</sup> IRC Chapter 4

<sup>23</sup> IRC 402.3.2

<sup>24</sup> IRC 402.4.2 Climate data

<sup>25</sup> IRC 401.1 General

<sup>26</sup> 402.1.3.2 Passive solar

<sup>27</sup> 402.1.3.3 Heat storage (thermal mass)

<sup>28</sup> IECC 402.1.3.5 Heating and cooling controls

<sup>29</sup> IECC Table 402.1.3.5 Heating and cooling controls

<sup>30</sup> IECC 402.5 Documentation, Exception

<sup>31</sup> NEC 110-2 Approval

<sup>32</sup> NEC 100 Definitions

<sup>33</sup> IRC 1302.1 Appliances

<sup>34</sup> IECC 403.1.1 Solar energy exclusion, one

## **4. Code Impacts by Technology**

### **4.1 Photovoltaic Systems in Buildings and Building-Integrated Photovoltaic Systems**

Three types of consideration that show compliance of PV systems with the codes will be discussed in this section:

- The electrical aspects of PV systems must comply with the appropriate sections of the NEC. The NEC is concerned mainly with safety issues, including electrical fires, electric shock, and other possible hazards.
- The PV systems must meet the structural and mechanical safety requirements of the IRC. This includes weather tightness, fire resistance, wind loading, access, roof penetrations, and similar issues.
- The energy analysis sections of the IECC are used to determine if proper energy load reductions are given to PV systems to help a building comply with the overall IECC requirements.

Presently, the relevant code language applicable to PV systems is spread throughout the various codes. The IRC should include a new chapter for PV systems. This allows practitioners in the PV field to easily locate all applicable code requirements. This new chapter should include references to the NEC Article 690, and other relevant language in the IRC, IMC, IPC and IECC.

#### **4.1.1 Photovoltaic Systems and the National Electrical Code**

The electrical-safety-related aspects of PV systems are extensively covered in Article 690 of the NEC and other Articles that it references. Note that this Article references many other Articles in the NEC, showing the range of knowledge that must be applied to install PV systems that comply with the code. The more relevant Articles in the NEC that apply to PV systems are presented in Table 1. However, the information in the NEC applies only to the electrical and electrical safety aspects of PV system installations. There is no mention in the NEC or the other codes about the building component aspects of PV systems.

A report from Sandia National Laboratories, entitled “Photovoltaic Power Systems and the NEC: Suggested Practices,”<sup>35</sup> presents an excellent treatment of the real-world electrical safety problems addressed by the NEC and encountered in the field. A list of the more common Code violations found in the field and listed in this report is presented below. Also included are the pertinent Articles in the NEC that address each problem and an explanation of how to correct the problem. Because of the complexity of the NEC, this list is not comprehensive and only highlights commonly found problems and their resolution within the NEC. Many of the problems presented are not strictly the difficulty of fitting PV technologies within the constraints of the NEC. Rather, they result from the lack of sophistication and formal electrical training of the installers and designers in the PV industry, the lack of experience that inspectors have

**Table 1. Partial List of Important Articles in the  
National Electrical Code for PV System Installations**

Article #	Title
110	Requirements for Electrical Installations
200	Use and Identification of Grounded Conductors
210	Branch-Circuit Ratings
220	Branch-Circuit, Feeder and Service Calculations
240	Overcurrent Protection
250	Grounding
300	Wiring Methods
310	Conductors for General Wiring
339	Underground Feeder and Branch-Circuit Cable, Type UF
384	Switchboards and Circuits Boards
445	Generators
480	Storage Batteries
705	Interconnected Electric Power Production Sources
720	Circuits and Equipment Operating At Less Than 50 Volts

with PV systems, and the small-market-related lack of UL listings for equipment specific to PV systems.<sup>36</sup>

- **Improper ampacity of conductors. [690-8, 690-31]** A great deal of information is presented in the NEC on how to correctly size conductors and other equipment. Conductor sizes depend on the maximum possible current, or ampacity, of the circuit. Wires between the modules and from the modules to their common connection point (the PV source circuit) are sized at 125% of the parallel-rated short-circuit current of the connected modules.<sup>37</sup> The extra 25% amperage is because the standard solar insolation conditions for rating the panels can be exceeded by the insolation actually found in the field. The ampacity of the solar PV output circuit (that wiring which, for example, leads directly into an inverter or direct-current loads) is the sum of the parallel source circuit maximum currents as rated above. The ampacity of the inverter output circuit between an inverter and the alternating current (AC) load center is the inverter maximum continuous output current rating. The ampacity of the inverter input circuit with no utility connection is the inverter continuous input current rating when the inverter is producing rated power at the lowest input voltage. The ampacity of conductors must also be derated if the conductors are exposed to temperatures above 30°C.<sup>38</sup> This can occur near modules. Temperatures of 60° to 70°C can reduce the ampacity by a factor of three.

- **Improper insulation on conductors. [690-31]** This article specifies the wire types that must be used for the various connections in a PV system. It specifies, for example, that any wire exposed to the sun must be rated as sunlight resistant. Flexible cords used to connect the moving parts of tracking PV modules must be identified as a hard service cord or portable power cable, shall be suitable for extra hard usage, listed for outdoor use, and be water and sunlight resistant. Battery cables can be flexible cables, but they must be listed for hard-service use and moisture resistant. Welding and automobile battery cables are not permitted.<sup>39</sup> The standard wire color coding for conducting wires is also often not followed in PV systems.<sup>40</sup>
- **Unsafe wiring methods. [Many]** The approved wiring methods described in various sections of Article 690 are often overlooked in the field. For example, 690-4(c) requires that the “removal of a module or panel from a PV source circuit does not interrupt a grounded conductor to another PV source circuit.” This means that “daisy-chain” wiring is prohibited, and a more expensive bus bar wiring scheme is required. Many more examples are presented in the Sandia Report<sup>41</sup>.
- **No overcurrent protection on many conductors. [690-9]** Essentially all PV system circuits need overprotection devices, such as fuses and circuit breakers. This can be overlooked in hybrid systems with multiple potential electric power sources, such as generators or wind powered generators. To prevent nuisance tripping, the ampacity of overcurrent protection devices must be at least 125% of the ampacity of the protected circuit.<sup>42</sup> Overcurrent protection devices in DC circuits must be rated and listed for the appropriate DC voltage and current.<sup>43</sup>
- **Inadequate number and placement of disconnects. [690-13 through 690-18]** Means need to be provided to disconnect all current carrying PV power source conductors from all other conductors in a building. Means also need to be provided to disconnect all equipment, such as inverters, batteries, charge controllers, and so forth, from all ungrounded conductors of all sources.
- **Use of non-approved components when approved components are available. [Various]** There are at least two factors that make it difficult for PV installers to always locate and use equipment and components that are listed for PV system applications. Much of the circuitry in PV systems is DC. Components that are DC-rated are not always readily available and price competitive with comparable AC-rated components. The relatively small number of PV systems provides an obstacle to the expensive testing required for UL certification of PV specific equipment and components. Local code officials are not likely to accept systems with inappropriate components.
- **Improper system grounding. [690-41 through 690-47]** PV systems need to be correctly grounded to reduce safety problems and electrical surges from lightning and other sources. The grounding conductor needs to be properly sized and connected at the proper location. The use of more than one ground will produce problems, including potential ground loop currents. Any exposed metal frames of module frames, equipment cases, junction boxes, and other conductor enclosures need to be grounded.

- **Unsafe use of batteries. [690-71]** Batteries present several types of safety hazards. First, the types of batteries used in PV systems can store a very large amount of energy. This energy can be very quickly released if the battery terminals are shorted. For this reason, batteries in PV systems in dwelling units are generally limited to 50 volts and must have guarded terminals and other live parts. Second, storage batteries can produce potentially explosive amounts of hydrogen gas during charging. Therefore, batteries need to be located in a ventilated area to prevent accumulation of an explosive mixture of hydrogen and air.<sup>44</sup> Batteries with vented cells need flame arresters. Sealed batteries need a pressure release vent to prevent excessive accumulation of gas pressure.

#### ***4.1.2 Photovoltaic Systems and Structural and Mechanical Requirements***

The PV industry and research communities developed and implemented Article 690 of the NEC to provide the compliance path for the electrical and electrical safety aspects of PV systems. No similar effort has been made for the structural and mechanical aspects of these systems. However, there are many sections scattered through the IRC and other codes that are relevant to these issues. These sections are described here, grouped into discussions on building structural loads, building weather tightness, access safety, and other related issues.

##### **Building Loads**

**Dead Loads.** A major purpose of the IRC is to present rules that ensure that building structures do not fail. “Buildings and . . . all parts thereof, shall be constructed to support safely all loads, including dead loads.”<sup>45</sup> Dead loads are defined as the “actual weight of materials and construction.”<sup>46</sup> The dead load for a roof includes all structural materials, weather barrier layers, and any permanent, roof-mounted structures. “Dead loads shall not exceed 15 PSF (pounds per square foot) for roofs . . . in Seismic Zone 4, roof dead loads shall not exceed 9 PSF.”<sup>47</sup> While the weight for calculation of the dead load is defined, the applicable roof area is not. While not strictly defined in the IRC, the purpose is to prevent both local and general failures of roof structures. Consequently, the structural designs for roof-mounted PV panels, support structures, batteries, or other auxiliary equipment should account for these requirements. Mounting frames and other structures should transfer dead loads directly to roof structural members. Any roof-mounted concentrated loads, such as batteries, should be designed on structures that distribute their weight over a large enough area to comply with these requirements. Engineering design of roof structures should include the loads from the weight of any PV system equipment. For example, for a wood-truss roof, “No additional loading of any member (e.g., HVAC equipment, water heater) shall be permitted without such additional load being incorporated in the engineering design.”<sup>48</sup>

**Wind Loads and Snow Loads.** PV modules, frames, and other structures on rooftops are subject to aerodynamic forces from high winds and the weight of accumulated snow. PV modules on roof mounted frames can also act as a “snow fence” and increase the local accumulation of snow. The IRC contains several sections to ensure that these

forces do not produce structural failure or glass breakage. Compliance requires sufficient structural design and material strength to prevent failure during extreme conditions.

Wind loading requirements are based on the exposure, the maximum expected wind speed, and the building height. Exposure classifications are “A/B” for built up and wooded areas, “C” for open terrain, and “D” for areas adjacent to large bodies of water. The design wind speeds are determined from a table in the IRC<sup>49</sup> or from locally derived information. Many areas, such as the Front Range of Colorado, are defined as “Special Wind Regions” because of high and variable maximum expected wind speeds. The design wind loads, in lb/ft<sup>2</sup> of “uplift,” are found in IRC Table 301.2b, Design Wind Loads. There are no design implications for wind speeds less than 81 miles per hour in A/B, less than 71 miles per hour in C, and less than 70 miles per hour in D.

There is no specific mention of structural considerations for frame-mounted PV modules in the IRC. However, “Buildings . . . with unusual constructions or geometric shapes . . . shall be designed in accordance with the provisions of ASCE 7-88<sup>50</sup>.”<sup>51</sup> In addition, “Construction in regions where reference wind speeds equal or exceed 90 mph shall be designed in accordance with” ASCE 7-88 or another standard.<sup>52</sup> It is reasonable to expect that local building inspectors in areas where wind loading is a design consideration for typical roof construction will require additional engineering documentation to show the adequacy of any rooftop structures and connections to roof structural members. If PV system installations increase the uplift from wind loading over an entire roof, there may be additional structural requirements for the roof and other framing members. “Roof assemblies subject to wind uplift pressures of 20 lb/ft<sup>2</sup> or greater, as established in Table 301.2b, shall have rafter or truss ties provided at bearing locations in accordance with Table 802.10. A continuous load path shall be provided to transmit the uplift forces from the rafter or truss ties to the foundation.”<sup>53</sup> Areas with 20 lb/ft<sup>2</sup> or more of wind force uplift are the same areas discussed in the previous paragraph. These structural requirements are a function of the geometric design, module slope angle, and the maximum expected wind speed. Such information can be developed for each installation at a high engineering cost. Standard designs will need to be engineered for the most stringent conditions or they will not be applicable for all locations. If information on site specific designs is readily available, it should be distributed to installers and other pertinent parties. If it is not available, then its development may be a reasonable research area for DOE or similar organizations.

There are also wind-loading restrictions on glazing that code officials may decide to apply to PV panels when their construction resembles a pane of glass. For glazing within 15 degrees of vertical, a formula is given that relates the length, width, thickness, and type of glass and how the glass is supported to the design wind loading.<sup>54</sup> Glass more than 15 degrees from vertical must be designed to also sustain snow loads, inward or outward wind loads, and the dead load of the weight of the PV panel.<sup>55</sup> The “allowable loads for glass thicker than ¼ inch shall be determined in accordance with ASTM E 1300.”<sup>56</sup> Even if Code officials do not require PV modules to meet the structural requirements for vertical or sloped glazing, it is in the best interest of the industry to prevent structural failures in the field. To help prevent these failures and to prevent Code compliance problems, manufacturers could supply maximum sustainable wind and snow loads for each size and model of panel based on recognized testing standards.

Snow loading involves the downward force from the weight of snow. PV modules and support frames need to be built strong enough to support these loads. A map of design snow load levels is presented in IRC Figure 301.2e, with a range from 0 to more than 80 lb/ft<sup>2</sup>. Local code officials can determine more stringent local requirements.<sup>57</sup>

Though not mentioned in the codes, the impact of rooftop-mounted PV systems on additional accumulation of snow should be considered. If the PV panels and frames tend to trap additional snow, then roof snow loads may be significantly higher than normal. The design of roof rafter systems depends on the maximum expected snow load. This snow load is “based on the higher of the ground snow load or the equivalent snow load converted from the wind speed.”<sup>58</sup>

IRC Table 804.3.3b presents the information needed to convert the wind speed to an equivalent snow load. In this table, steeper sloped roofs have a higher equivalent snow load than shallower ones with the same design wind speed and exposure. There are potential implications here for roof-mounted PV systems with steeper slopes than the supporting roof structure. This is another possible area for research by DOE or other interested organizations. The impact of increased effective snow loads is to decrease the allowable spans for a given rafter size and on center spacing.<sup>59</sup>

If installations of PV panels or products are similar to skylights or sloped glazing, then additional compliance constraints may also apply.<sup>60</sup> This could include PV-powered electrochromic windows. For an “installation of glass or other transparent or translucent glazing material installed at a slope of 15 degrees or more from vertical,”<sup>61</sup> only certain types of glazing materials may be used. These include “Fully tempered glass, Heat-strengthened glass, Wired glass and Approved rigid plastics.”<sup>62</sup> There is no list of “Approved rigid plastics.” However, in the IRC, approved “refers to approval by the code official as the result of investigation and tests conducted by him, or by reason of accepted principles or tests by nationally recognized organizations.”<sup>63</sup> Rigid plastic materials in such PV applications would need to meet the testing standards for exterior glazing, such as CPSC 16 CFR 1202<sup>64</sup> or a similar standard. Additionally, “Laminated glass with a minimum 0.015-inch polyvinyl butyral interlayer for glass panes 16 ft<sup>2</sup> or less in area; for larger sizes, the minimum interlayer thickness shall be 0.030 inch.”<sup>65</sup> This is “safety glass,” designed to break into small, rounded pieces upon shattering. The specific interlayer material requirements are quite constraining, as this material is not presently used in PV products. Language could be added to this section to read:

**308.8.2 Permitted materials.** Laminated glass with a minimum 0.015 inch polyvinyl butyral interlayer for glass panes 16 ft<sup>2</sup> or less in area; for larger sizes, the minimum interlayer thickness shall be 0.030 inch. Alternate materials can be used for the interlayer if it provides comparable performance as confirmed by testing under CPSC 16 CFR 1202 or a comparable standard.

**Human Impact Loads.** The IRC restricts glazing used in areas where there is increased chance of direct human contact resulting in glass breakage. A large number of rules and exceptions define the hazardous locations where these restrictions apply.<sup>66</sup> If any PV products are installed in these areas, they will need to comply with the test requirements of CPSC 16 CFR 1201.<sup>67</sup>

## Weather Tightness

Attachments to the outside of buildings must prevent moisture from entering. Compliance with several sections of the IRC is relevant to these issues.

**Roof penetrations.** The IRC section on active solar hot-water systems states that “Roof penetrations, including piping and electric wiring, needs to be flashed and waterproofed in accordance with Chapter 9” of the IRC.<sup>68</sup> The purpose here is to prevent roof leaks. Applied to PV systems, this would logically apply to the attachment points for the support frames, as well as the electrical wiring penetrations. “Flashings shall be installed . . . around roof openings.”<sup>69</sup> There are further requirements for flashing depending on the type of roof covering; for example, for asphalt shingles, “flashing shall be installed in accordance with manufacturer’s installation instructions.”<sup>70</sup>

**Penetrations between separate dwelling units.** While not concerned with weather tightness, there is a requirement in the IRC for wiring and piping penetrations between dwelling units in a multi-dwelling building. “Penetrations shall be fire resistant rated in accordance with sections 320.1 and 320.2. The through penetration firestop systems tested in accordance with ASTM E 814<sup>71</sup> with a minimum positive pressure differential of 0.01" of water. The firestop shall have an "F" rating not less than required for the penetrated assembly.” There are a number of exceptions where this does not apply. These requirements are to prevent the spread of fire from one dwelling unit to an adjacent unit.

**Roof covering materials.** “Roof decks shall be covered with approved roof coverings secured to the building or structure . . .”<sup>72</sup> Approved is defined as approved “by the code official as the result of investigation and tests conducted by him, or by reason of accepted principles or tests by nationally recognized organizations.”<sup>73</sup> At least two PV products, PV shingles and PV roof panels, are designed to replace traditional roofing materials as well as provide electric power. These products need to meet the code requirements for the types of roofing materials that they replace.

PV shingles are designed to replace flexible asphalt shingles. For these products, the requirements for asphalt shingles should reasonably apply.<sup>74</sup> Asphalt shingles shall only be used on roof slopes of 2-in-12 or greater.<sup>75</sup> They are not listed for roofs with lesser slopes.<sup>76</sup> If the shingles are appropriate for installation on roofs with lesser slopes, then additional language needs to be included in the IRC. This language should specify that PV shingles can be applied to roofs with slopes of less than 2-to-12, and should also describe any requirements that are specific to these applications. The following are some of the requirements for the installation of asphalt shingles and will apply to similar installations of PV shingles.

- “Asphalt shingles shall be fastened to solidly sheathed decks.”<sup>77</sup>
- “For roof slopes from . . . 2:12 to . . . 4:12 . . . double underlayment application is required. . . .”<sup>78</sup>
- “Asphalt shingles shall have self-seal strips or be interlocking, and comply with ASTM D 225<sup>79</sup> or D 3462.<sup>80,81</sup> These standards apply to mineral surfaced shingles, and a separate standard may need to be developed for the PV shingles. If a new

standard is required, then language to include it in the IRC will also need to be developed.

The remaining sections on asphalt shingles cover the types and numbers of needed fasteners in typical and high-wind areas, how the underlayment is applied, protection against ice buildup, and the proper installation of flashings. Identical requirements may apply to PV shingles.<sup>82</sup> However, the different physical characteristics of PV and asphalt shingles may require changes in or additions to the requirements of IRC Section 905 when applied to PV shingles. This is an area of possible research for DOE or an interested standards or manufacturer's organization.

Roofing materials are also subject to additional requirements. "Roof coverings shall be applied in accordance with this chapter and the manufacturer's installation instructions."<sup>83</sup> "Roofs and roof coverings shall be of materials that are compatible with each other and with the building or structure to which the materials are applied."<sup>84</sup> There is no definition for "compatible" in the IRC. This probably means that materials will not cause corrosion or other degradation in other building materials. An additional requirement is that roofing "shall conform to UL 790 and shall be installed in areas designated by law as requiring their use . . . ."<sup>85</sup> This refers to a testing standard for fire resistance. In the absence of applicable standards or where materials are of questionable suitability, testing by an approved testing agency shall be required by the code official to determine the character, quality and limitations of application of the materials."<sup>86</sup> Additionally, "Roof covering materials shall be delivered in packages bearing the manufacturer's identifying marks and approved testing agency labels when required."<sup>87</sup>

PV roof panels are designed to replace metal roofing products. In the IRC, metal roof shingles<sup>88</sup> are approved for use on roofs with slopes more than 2-in-12 slope, and metal roof panels<sup>89</sup> are approved on roofs with lesser slopes.

Requirements for metal roof shingles are similar to those for the asphalt shingles previously described. Specific requirements are that "metal roof shingle roof coverings of galvanized steel shall be 0.013 inch minimum thickness. Metal roof shingle roof coverings of aluminum shall be of 0.024 inch minimum thickness."<sup>90</sup>

Requirements for metal roof panels include:

- "Metal roof panel roof coverings shall be applied to a solid or space sheathing, except where the roof covering is specifically designed to be applied to space supports."<sup>91</sup>
- "The minimum slope for lapped, non-soldered, seam metal roofs shall be ... 3:12. The minimum slope for standing seam roof systems shall be ... 1/4:12."<sup>92</sup> This minimum requirement should be reviewed by manufacturers in regards to water collection that may present possible electrical problems.
- "Metal-sheet roof covering systems that incorporate supporting structural members shall be designed in accordance with the IBC."<sup>93, 94</sup>
- Metal-sheet roof coverings installed over structural decking shall comply with Table 906.4.3."<sup>95</sup> This table presents standards for various metal roofing materials. It should be referred to for specific PV roof panel materials.

Until the IRC includes requirements specific to PV shingles and PV roof panels, code officials can use the IRC to restrict their installation on buildings.

**Considerations for application to existing roofs.** PV shingles cannot be applied to more than 25% of a roof with an existing roof covering, unless “the entire roof covering is made to conform to the requirements for a new roof.”<sup>96</sup>

In a retrofit, the “structural roof components shall be capable of supporting the roof covering system and the material and equipment loads that will be encountered during installation of the roof covering system.”<sup>97</sup>

Under certain circumstances, the existing roof coverings will need to be removed before a new roof covering is applied.<sup>98</sup> These include:

1. “Where the existing roof or roof covering is water soaked or had deteriorated to the point that the existing roof or roof covering is not adequate as a base for additional roofing.”
2. “Where the existing roof covering is wood shake, slate, clay, cement or asbestos-cement tile.”
3. “Where the existing roof has two or more applications of any type of roof covering.”
4. “When the building is located in areas subject to hail damage according to Figure 909.3.”

An exception is allowed if the new roof covering system is designed to transmit structural loads directly to the building’s structural system.

## Access and Safety

There is concern that the codes may require expensive safety devices around roof-mounted PV arrays. There are no regulations in the codes reviewed for this report that directly require these devices. However, the IMC does require safety devices for roof-mounted “equipment and appliances.”<sup>99</sup> In the IMC, equipment is defined as everything “other than appliances which are permanently installed and integrated to provide control of environmental conditions for buildings.”<sup>100</sup> Appliances are defined as “A device or apparatus that is manufactured and designed to utilize energy and for which this code provides specific requirements.”<sup>101</sup> The scope statement for the IMC states that it regulates “mechanical systems that are permanently installed and utilized to provide control of environmental conditions and related processes within buildings. This code shall also regulate those mechanical systems, system components, equipment and appliances specifically addressed in this code.”<sup>102</sup> There is no mention in the IMC of PV systems. There seems to be no requirements in the IMC or other codes reviewed in this report about Access and Safety that have jurisdiction over PV systems.

However, the final arbiter of code enforcement is the local code official. Because code officials may view roof-mounted PV equipment as similar to roof-mounted mechanical equipment, the PV community should be aware of possibly applicable sections of the codes.

**Access.** The NEC requires that “sufficient access and working space shall be provided and maintained about all electric equipment to permit ready and safe operation and maintenance of such equipment.”<sup>103</sup> Generally, the working space requires a minimum of 30 inches of free area.<sup>104</sup> This is directly applicable to PV systems. There are similar requirements in the IMC. Therefore, rooftop PV equipment must be installed to allow access to any part that may need future maintenance. This includes all wiring connections and other components. This NEC requirement could cause the local code officials to require compliance with the following to mitigate potential safety problems.

**Guards.** Guards need to be installed where mechanical equipment is within 10 feet of a roof edge or open side of a walking surface and the edge is more than 30 inches above grade.<sup>105</sup> There are specific requirements for the construction of the guardrail.

**Equipment and appliances on roofs or elevated structures.** Mechanical equipment installed on roofs or elevated structures more than 16 feet above grade are required to have an approved, permanent means of access. This access allows no obstructions of more than 30 inches or walking on roofs with a slope greater than 4-in-12.<sup>106</sup> If applied to PV systems, this could require ladders, roof hatches, and so forth.

**Sloped roofs.** Mechanical equipment installed on roofs with a slope greater than 3-in-12 and having an edge more than 30 inches above grade at the edge requires a level platform for each side of the equipment that requires access for service, repair, or maintenance. The platform needs to be at least 30 inches in any dimension. Guards need to be provided as previously described.<sup>107</sup>

If enforced for PV systems, these requirements could provide a major economic and architectural obstacle to their widespread implementation. It must be remembered that these requirements arose from real safety issues during the maintenance of mechanical systems. The problem for the PV industry is to include language in the codes that specifically exempt their systems from these requirements or to otherwise provide data that will convince local code officials that these requirements are unnecessary.

## Other Structural and Mechanical Issues

A number of other regulations in the codes could apply to rooftop PV systems.

**Height limitations.** Wood-framed buildings are generally limited to three stories above grade. Cold-formed, steel-frame buildings are limited to two stories. Buildings in Seismic Zone 4 are limited to two stories above grade.<sup>108</sup> There is no discussion in the codes as to the impact on these height limitations of additional rooftop-mounted structures. Many localities have height limitation regulations that may impact structures adding to the overall building height. This could impact roof-mounted PV systems and equipment.

**Hazardous locations.** Hazardous locations are defined in the NEC as “locations where fire or explosion hazards may exist due to flammable gases or vapors, flammable liquids, combustible dust, or ignitable fibers. . . .”<sup>109</sup> There are special and expensive requirements for wiring and components that help to eliminate the possible fire or explosion hazards in these locations.<sup>110</sup> It is not likely that rooftop PV equipment will be

located near such hazards. However, batteries and other system components could be located in garages or other areas where these hazards could exist.

**Rooftop structures: Towers, spires, domes, and cupolas.** These structures must be as fire resistant as the building to which it is attached.<sup>111</sup> This could also apply to structures designed to architecturally integrate PV arrays into a building design.

#### **4.1.3 Photovoltaic Systems and Systems Analysis of the IECC**

In the IRC, credit for electric energy from PV systems is allowed. However, the steps necessary to calculate and document this energy credit are generally expensive and complex. It is in the interest of PV manufacturers and other interest groups to make compliance with the IECC an easier process.

In the IECC, renewable energy sources are defined as “sources of energy ... derived from incoming solar radiation.”<sup>112</sup> There is no mention of RE sources, including PV electricity, in the IECC prescriptive compliance path.<sup>113</sup>

The IECC performance path contains provisions to account for PV-generated electric power. “Renewable energy shall be permitted to be excluded from the total energy consumption allowed for the building. . . .”<sup>114</sup> This energy must “be derived from a specific collection, storage, and distribution system.”<sup>115</sup> While not intended, this may exclude PV systems without storage, such as utility connected systems, from energy credits in this analysis. A separate definition should be developed for PV systems, such as:

**IRC 403.1.4 Photovoltaic energy exclusion.** Electrical energy from solar photovoltaic systems shall be permitted to be excluded from the total energy consumption allowed for the building. This electrical energy must be used in the building to displace purchased electrical energy.

An interesting question is if credit should be given for electrical energy from PV systems that are sold back or otherwise transferred to the utility grid. If the total annual production of the PV system is less than that required in the standard building design, it appears to be reasonable to allow credit for the entire amount produced. However, if the PV system produces more electrical energy than the house requires, the PV system then becomes an electrical generator and not just part of a house. It does not appear reasonable that this excess energy should be credited to the house design.

The IECC analysis procedures are designed to calculate envelope thermal loads and resulting HVAC equipment performance.<sup>116</sup> The referenced design methods likewise do not have provisions for the calculation of PV system performance, either in general or as applied to a specific building.<sup>117</sup>

There presently appears to be no method to legally allow credit from PV generated electricity in either the prescriptive or performance paths in the IECC. This could be a major impediment to the implementation of this technology. Consequently, several activities could be undertaken to attack this problem.

- Analysis tools could be developed to allow, as appropriate, prescriptive path compliance in the IECC. These tools could be implemented in maps or tables that

relate annual PV production to collector performance parameters, location, and collector orientation. A prescriptive path analysis tool would likely be adequate for most PV system installations. It is also likely that such a tool could be easily derived from existing research products from DOE, the PV industry, and similar sources.

- There is presently no widely used analysis program that integrates PV system performance with a detailed building simulation. This strategy could be implemented in the development of add-ons to appropriate building energy analysis tools that add the simulation of PV system performance to these tools. It would also be necessary to develop standard profiles and area based power densities for residential electric and thermal internal gains. For the IECC performance path, only a constant value internal gain is specified, which presumably accounts for both electrical and thermal sources.<sup>118</sup> Such a program would allow the simultaneous analysis of a wide number of EE and RE technologies. This program would meet the analysis requirements of the IECC performance path. It would also allow the integration and design optimization of the wide range of these technologies.
- Language needs to be added to IECC Chapters 4 and 5 to allow credit for these proposed analysis methods.

There needs to be a report detailing the proposed design and analysis.<sup>119</sup> If RE is used, it needs to be separately identified from the overall building energy use. Supporting documentation needs to be submitted.

Another issue with energy credits for PV systems involves the IECC requirement that electricity and other energy sources are treated equivalently.<sup>120</sup> In general, energy in the form of electricity is more expensive than other types of energy. This puts PV and other alternative electricity sources at a disadvantage relative to energy credits in the IECC.

Finally, though certainly not least, buildings less than 20,000 ft<sup>2</sup> that derive at least 30% of their annual energy from RE are exempt from a full-year energy system.<sup>121</sup> It is not clear what is meant by this confusing language. This represents a free bonus to some RE technology implementations, as it appears to exempt them from the detailed analysis required in the rest of Chapter 4. However, there is no discussion how this 30% figure is to be calculated nor how compliance with this code language is to be established.

#### **4.1.4 Summary of Codes and Standards for PV Systems**

The following Table presents an overview of the sections of the reviewed codes and existing standards that apply to PV systems. Note that blank cells in the table can represent areas where additional standards and code language may need to be developed.

**Table 2. Summary of Standards and Reviewed  
Code Sections Relevant to PV Systems**

<b>Table 2.</b>	<b>Performance</b>	<b>Safety</b>	<b>Operation</b>	<b>Maintenance</b>
<b><i>Electrical Requirements</i></b>				
PV Module	IEEE 1262	UL 1703	NEC 690/IEEE 929	Manufacturer's Instructions
Inverter		UL 1741	NEC 690/IEEE 929	Manufacturer's Instructions
Other Electrical Components		UL (various)		Manufacturer's Instructions
PV System				
PV Shingles	IEEE 1262	UL 1703	NEC 690/IEEE 929	Manufacturer's Instructions
PV Roof Panels	IEEE 1262	UL 1703	NEC 690/IEEE 929	Manufacturer's Instructions
<b><i>Structural and Weather Sealing Requirement</i></b>				
Weather Sealing and Penetrations	na	IRC Section 903	na	Manufacturer's Instructions
Racks	na		na	Manufacturer's Instructions
PV Shingles	na	IRC Section 905.2	na	Manufacturer's Instructions
PV Roof Panels	na	IRC Section 905.4, 906.4	na	Manufacturer's Instructions

## **4.2 Active Solar Domestic Hot Water and Space-Heating Systems**

Four types of considerations show compliance of active solar hot water (SHW) and space-heating with the codes. First, there are chapters on active solar systems in the IRC and the IMC. Second, the plumbing, mechanical, and electrical system aspects of SHW systems must comply with the appropriate sections of the IRC, IMC, IPC, and the NEC not covered in the previous discussion. Third, SHW systems must meet the structural and mechanical safety requirements of the IRC. This includes weather tightness, fire resistance, wind loading, access, roof penetrations, and similar issues. Finally, the energy analysis sections of the IECC are used to determine if proper energy load reductions are

given to SHW systems to help a building comply with the overall IECC requirements. These issues are discussed in the following sections.

The code issues of SHW systems are also addressed in the SRCC Document OG-300.<sup>122</sup> This document is not part of the IRC or other codes referenced in this report. The OG-300 will be discussed separately in Appendix A of this report. It is much wider in scope and brings together in one place many of the Code issues relevant to SHW systems that are dispersed throughout the IRC and other referenced codes.

The requirements of the IRC Chapter 27 and the IMC Chapter 15 directly apply to SHW systems. Topics from these Chapters and other areas of the referenced codes are discussed.

Presently, the relevant code language applicable to SHW systems is spread throughout the various codes. The IRC chapter on solar systems<sup>123</sup> should include all of the information applicable to SHW applications. This allows practitioners in the SHW field to easily locate all applicable code requirements. This revised chapter should include references to the relevant language in the IRC, IMC, IPC, IECC, and the NEC.

## Access and Safety

There is concern within the RE community that the codes may require expensive safety devices around roof-mounted SHW collectors. There are no regulations in the codes reviewed for this report that directly require these devices. However, the IMC does require safety devices for roof-mounted “equipment and appliances.”<sup>124</sup> In the IMC, equipment is defined as everything “other than appliances which are permanently installed and integrated to provide control of environmental conditions for buildings.”<sup>125</sup> Appliances are defined as “A device or apparatus that is manufactured and designed to utilize energy and for which this code provides specific requirements.”<sup>126</sup> The scope statement for the IMC states that it regulates “mechanical systems that are permanently installed and utilized to provide control of environmental conditions and related processes within buildings. This code shall also regulate those mechanical systems, system components, equipment, and appliances specifically addressed in this code.”<sup>127</sup>

The final arbiter of code enforcement is the local code official. Because code officials may view roof-mounted SHW equipment as similar to roof-mounted mechanical equipment, the SHW community should be aware of possibly applicable sections of the codes.

**Access.** Solar hot water system components “shall be accessible for inspection, maintenance, repair and replacement.”<sup>128</sup> Accessible “signifies access that requires removal of an access panel or similar removable obstruction.”<sup>129</sup> Readily accessible signifies access without the necessity of removing a panel or similar obstruction.”<sup>130</sup> The former is more restrictive. Therefore, active SHW system components must be accessible either with or without removal of a panel or similar obstruction. An exception is “live parts of electrical equipment operating at 50 volts or more shall be guarded against accidental contact by approved enclosures” or other means.<sup>131</sup> “Thirty inches of working space shall be provided in front of the control side to service an appliance.”<sup>132</sup>

An appliance is defined as a “device or apparatus that is manufactured and designed to utilize energy and for which this code [IRC] provides specific requirements.”<sup>133</sup>

The terms “equipment” and “appliance” are used seemingly interchangeably in IRC section 1305. Equipment is defined as “materials, fittings, devices, appliances and apparatus used as part of or in connection with installations regulated by this code.”<sup>134</sup> There are specific clearance requirements for equipment in rooms, including basements or similar spaces.<sup>135</sup> There must be an “opening or door and an unobstructed passageway measuring not less than 24 inches wide and large enough to allow removal of the largest appliance in the space.” There are also specific requirements for access to equipment in attics that require access.<sup>136</sup> If equipment in the attic cannot be serviced “through the required opening,” then a passageway with “solid continuous flooring . . . not less than 24 inches wide” is required for access. The equipment and appliances for which the IRC provides specific requirements include roof-mounted collectors, pressure- and temperature-relief valves, vacuum-relief valves, freeze-protection devices, expansion tanks, thermal storage units, and backflow protection devices. Presumably, local code officials would require adequate access and appropriate working space, as described above, for these and all other SHW components that may require maintenance, removal, or replacement. It would be useful if additional language describing all these requirements were included in the IRC and IMC solar system chapters.

**Guards.** Guards need to be installed where mechanical equipment is within 10 feet of a roof edge or open side of a walking surface and the edge is more than 30 inches above grade.<sup>137</sup> There are specific requirements for the construction of the guardrail.

**Equipment and appliances on roofs or elevated structures.** Mechanical equipment installed on roofs or elevated structures more than 16 feet above grade are required to have an approved, permanent means of access. This access allows no obstructions larger than 30 inches or walking on roofs with a slope greater than 4-in-12.<sup>138</sup> If applied to SHW systems, this could require ladders, roof hatches, and so forth.

**Sloped roofs.** Mechanical equipment installed on roofs with a slope greater than 3-in-12 and having an edge more than 30 inches above grade at the edge require a level platform for each side of the equipment that requires access for service, repair, or maintenance. The platform needs to be at least 30 inches in any dimension. Guards need to be provided as previously described.<sup>139</sup>

If enforced for SHW systems, these requirements could provide a major economic and architectural obstacle to their widespread implementation. It must be remembered that these requirements arose from real safety issues during the maintenance of mechanical systems. The problem for the SHW industry is to include language in the codes that specifically exempt their systems from these requirements or to otherwise provide data that will convince local code officials that these requirements are unnecessary.

**Roof-mounted collectors and roof structural loads.** “The roof shall be constructed to support the loads imposed by the roof-mounted solar collectors.”<sup>140</sup>

Some designs of active SHW systems, such as those with a roof-located water storage tank, can produce highly concentrated roof loading. Higher weights are more likely to reach the roof dead load limitations of 15 PSF (and 9 PSF in seismic areas). While

calculation of the maximum weight of these systems is relatively easy to determine, the applicable area is not. The roof structure needs to be designed and built to prevent both general and local failure. Loads over small areas need to be solidly supported and the structure “shall transmit the resulting loads to its supporting structural elements.”<sup>141</sup> If active SHW systems are installed on existing buildings, the roof structure may need to be evaluated to determine if excessive loading is a problem. Guidelines for the proper approach to this issue may be an appropriate area for DOE research.

Wind-loading requirements for SHW systems are specified in the IMC. “Mechanical equipment, appliances and supports that are exposed to wind shall be designed and installed to resist the wind pressures determined in accordance with the building code.”<sup>142</sup>

**Roof-mounted collectors as roof coverings.** “Roof decks shall be covered with approved roof coverings secured to the building or structure . . .”<sup>143</sup> Approved is defined as approved “by the code official as the result of investigation and tests conducted by him, or by reason of accepted principles or tests by nationally recognized organizations.”<sup>144</sup> If SHW collectors are designed to replace traditional roofing materials as well as provide hot water, then these products need to meet the Code requirements for the types of roofing materials that they replace.

“Roof coverings shall be applied in accordance with this chapter and the manufacturer’s installation instructions.”<sup>145</sup> “Roofs and roof coverings shall be of materials that are compatible with each other and with the building or structure to which the materials are applied.”<sup>146</sup> There is no definition for “compatible” in the IRC. This probably means that materials will not cause corrosion or other degradation in other building materials. An additional requirement is that roofing “shall conform to UL 790 and shall be installed in areas designated by law as requiring their use . . .”<sup>147</sup> This refers to a testing standard for fire resistance. In the absence of applicable standards or where materials are of questionable suitability, testing by an approved testing agency shall be required by the code official to determine the character, quality, and limitations of application of the materials.”<sup>148</sup> Additionally, “Roof covering materials shall be delivered in packages bearing the manufacturer’s identifying marks and approved testing agency labels when required.”<sup>149</sup>

SHW collectors could be designed as roof panels designed to replace metal roofing products. In the IRC, metal roof shingles<sup>150</sup> are approved for used on roofs with slopes more than 2-in-12, and metal roof panels<sup>151</sup> are approved on roofs with lesser slopes.

Specific requirements are that “metal roof shingle roof coverings of galvanized steel shall be 0.013 inch minimum thickness. Metal roof shingle roof coverings of aluminum shall be of 0.024 inch minimum thickness.”<sup>152</sup>

Requirements for metal roof panels include the following:

- “Metal roof panel roof coverings shall be applied to a solid or spaced sheathing, except where the roof covering is specifically designed to be applied to space supports.”<sup>153</sup>
- “The minimum slope for lapped, non-soldered seam metal roofs shall be ... 3:12. The minimum slope for standing seam roof systems shall be ... 1/4:12.”<sup>154</sup> This

minimum requirement should be reviewed by manufacturers in regards to water collection that may present possible electrical problems.

- “Metal-sheet roof covering systems that incorporate supporting structural members shall be designed in accordance with the IBC.”<sup>155</sup>
- Metal-sheet roof coverings installed over structural decking shall comply with Table 906.4.3.”<sup>156</sup> This table presents standards for various metal roofing materials. It should be referred to for specific roof panel materials.

Until the IRC includes requirements specific to SHW roof systems, code officials can use the IRC to restrict their installation on buildings.

**Considerations for application to existing roofs.** New roof coverings cannot be applied to more than 25% of a roof with an existing roof covering, unless “the entire roof covering is made to conform to the requirements for a new roof.”<sup>157</sup>

In a retrofit, the “structural roof components shall be capable of supporting the roof covering system and the material and equipment loads that will be encountered during installation of the roof covering system.”<sup>158</sup>

Under certain circumstances, the existing roof coverings will need to be removed before a new roof covering is applied.<sup>159</sup> These include the following:

- “Where the existing roof or roof covering is water soaked or had deteriorated to the point that the existing roof or roof covering is not adequate as a base for additional roofing.”
- “Where the existing roof covering is wood shake, slate, clay, cement or asbestos-cement tile.”
- “Where the existing roof has two or more applications of any type of roof covering.”
- When the building is located in areas subject to hail damage according to Figure 909.3.”

An exception is allowed if the new roof covering system is designed to transmit structural loads directly to the building’s structural system.

**Roof-mounted collectors and fire prevention.** “When mounted on or above the roof coverings, the collectors and supporting structure shall be constructed of noncombustible materials or fire-retardant-treated wood equivalent to that required for the roof construction.”<sup>160</sup> These materials must meet the requirements of UL 790.<sup>161</sup> Metal-framed collector panels with glass glazing will not create a fire hazard. However, flammable materials used for gaskets or other components may be a problem.

There may be restrictions in the types of plastics that can be used for solar collectors. “The use of plastic solar collector covers shall be limited to those approved plastics meeting the requirement for plastic roof panels in the building code.”<sup>162</sup> There is no information in the IRC on plastic roof panels. The IRC does have requirements for a variety of plastic and plastic-like materials. These include thermoset single-ply roof coverings,<sup>163</sup> thermoplastic single-ply roofing,<sup>164</sup> sprayed polyurethane foam roofing,<sup>165</sup> and foam plastics.<sup>166</sup> All of these materials are applied in monolithic layers on roofs.

However, the fire resistance requirements in the referenced standards are likely similar to those needed for the materials found in plastic solar collectors. Because the requirements for the materials in plastic solar collectors are not in the IRC, the local code officials may need to be convinced that the fire resistance and other properties of these collectors are comparable to that of approved roof coverings. It will be easier to convince local code officials of the appropriateness of their products if the manufacturers and other constituents of these products develop an applicable standard and test their products to that standard.

## Plumbing Requirements

Most of the components in active SHW systems are plumbing components, which come under the requirements of some sections of the IRC, the IMC, and the IPC. The plumbing components with code requirements in the Solar Systems sections of the IRC and IMC will be considered first.

**Pressure and temperature relief.** Fluid-containing components must be protected with pressure and temperature relief valves. The system must be designed to prevent the isolation of sections of the system from the relief devices.<sup>167</sup> The relief valves “shall bear the label of an approved testing agency and shall have a temperature setting of not more than 210°F and a pressure setting not exceeding the tank . . . working pressure or 150 psi, whichever is less. The relieving capacity of each pressure relief valve and each temperature relief valve shall equal or exceed the heat input to the water heater or storage tank.”<sup>168</sup> Additional requirements apply to the size of the discharge pipe from the relief valve, where it goes, how to protect it from freezing, and other requirements.<sup>169</sup> Any pipe material listed as suitable for water service pipe can be used for the discharge piping. There is no code language specifying that the discharge piping from each relief valve be separately piped to the outside or an appropriate drain. However, this may be an issue of concern to local code officials.

**Vacuum relief.** If any system components can experience sub-atmospheric pressures when in operation or shutdown, they must be protected with a vacuum-relief valve.<sup>170</sup> There do not appear to be any additional requirements that specify the design or performance of relief valves. The IMC Solar Systems chapter requirement is similar, but states that such a system “shall be designed to withstand such vacuum or shall be protected with vacuum relief valves.”<sup>171</sup> This allows more flexibility if other technical approaches are available.

**Protection from freezing.** Any system components subject to the freezing of heat-transfer fluids need to be protected from associated damage.<sup>172</sup> This language includes the use of low-freezing-temperature heat-transfer fluids for freeze protection. Reference is made that protection from freezing can be “by insulation or heat or both.”<sup>173</sup> There is no direct reference to the emptying of piping and components with the approach of freezing temperatures, as is done with draining-type SHW systems. It would be useful to add language in the IRC Solar Systems chapter to more explicitly define the acceptable options.

**IRC 2701.2.5.1** Acceptable freeze protection methods. Freeze protection shall be provided by heating, insulation, suitable low freezing point fluids,

draining of piping and other components, or an appropriate combination of these methods.

**Expansion tanks.** The IRC treats SHW systems as boilers in regards to expansion tanks.<sup>174</sup> Expansion tanks can be either non-pressurized or pressurized depending on the system design. Both types must meet the minimum capacity requirements of IRC Table 2302.2.<sup>175</sup> Non-pressurized tanks are appropriate for draining systems that operate at atmospheric pressure. These are likely required even if the system is designed to accommodate the fluid expansion independent of an expansion tank. The IRC could be changed to provide for such systems.

**2701.2.6.1 Exception.** Non-pressurized, draining solar hot water systems do not need expansion tanks if the system is designed to accommodate the expansion volumes under “Nonpressurized Type” in IRC Table 2302.2.

There are specific requirements for the location, structural support, and overflow discharge requirements of non-pressurized tanks.<sup>176, 177</sup>

**Collectors.** SHW collectors “shall be listed and labeled to show the manufacturer’s name, model, serial number, collector weight, maximum allowable temperatures and pressures, and the type of heat transfer fluids allowed.”<sup>178</sup> Listed refers to equipment that has been tested by an approved testing agency to meet nationally recognized standards.<sup>179</sup> At least one researcher claims that the type of heat transfer fluids allowed should not be an issue with the collector or other components.<sup>180</sup> He states that this should be a system level issue and appropriate labels should be applied to the system drain and fill valves. It seems appropriate that any heat transfer fluids that are not compatible with the collector materials, such as those that cause corrosion, should be labeled on the collector. Fluids that are not compatible with the piping and materials found in other SHW plumbing components or prohibited heat transfer materials could be labeled at the fill and drain valves.

The IRC and other referenced codes have no requirements to label collectors with results from standardized performance tests.

**Thermal storage units.** “Pressurized thermal storage units shall be listed and labeled to show the manufacturer’s name, model, serial number, maximum and minimum allowable operating temperatures and pressures, and the type of heat transfer fluids allowed.”<sup>181</sup> The allowable fluids listing issue is the same as for collectors above. There are no requirements for non-pressurized thermal storage tanks, as would be used in some draining SHW systems.

The IPC has requirements for minimum insulation levels for water heater storage tanks. They “shall be insulated so that heat loss is limited to a maximum of 15 BTH/h/ft<sup>2</sup> of external tank surface area. . . . the design ambient temperature shall not be higher than 65°F.”<sup>182</sup> This equates to a water to air R-value of about 9.7. Additional requirements for water heater tanks are in the IECC, which may be applicable and more stringent than those in the IPC.<sup>183</sup> It would be useful to include this in the IRC Solar Systems chapter.

**2701.3.2.1 Thermal storage unit insulation levels.** Thermal storage units shall be insulated so that heat loss is limited to a maximum of 15

BTH/h/ft<sup>2</sup> of external tank surface area. For design purposes, the design ambient temperature shall not be higher than 65°F. This equates to a minimum water to air R-value of about 9.7.

**Prohibited heat-transfer fluids.** Flammable gases and liquids cannot be used as heat-transfer fluids.<sup>184</sup> Flammable liquids are defined as having “a flash point below 100°F.”<sup>185</sup> The flash point is “the minimum temperature . . . at which the application of a test flame causes the vapors of a portion of the sample to ignite under “standardized test conditions.”<sup>186</sup> The flash point then is the minimum temperature at which the vapors from a liquid will ignite. The IMC allows liquids with flash points above 100°F to be used, as long as the flash point temperature is less than the highest of temperature conditions listed in the IMC.<sup>187</sup>

**Backflow protection.** The purpose of backflow prevention is that “potable water systems shall be protected against contamination in accordance with the plumbing code.”<sup>188</sup> Potable water is defined as “water free from impurities present in amounts sufficient to cause disease or harmful physiological effects and conforming in . . . quality to the requirements of the . . . public health authorities having jurisdiction.”<sup>189</sup> “The potable water supply to a solar system shall be equipped with a backflow preventer with intermediate atmospheric vent complying with ASSE/ANSI 1012<sup>190</sup> or a reduced pressure principle backflow preventer complying with ASSE/ANSI 1013<sup>191</sup>. Where chemicals are utilized, the potable water supply shall be protected by a reduced pressure principle backflow preventer.”<sup>192</sup> “Heat exchangers utilizing an essentially toxic transfer fluid shall be separated from the potable water by double-wall construction. An air gap open to the atmosphere shall be provided between the two walls. Heat exchangers utilizing an essentially nontoxic transfer fluid shall be permitted to be of single-wall construction.”<sup>193</sup>

This language is confusing and the requirements may be excessive and redundant to other requirements for some SHW system designs. The definition of potable water can be interpreted in two ways. Does it refer to the potable water supply before it enters the house, or does it also include the potable water piping, both hot and cold, in the house? How this is interpreted affects system design choices and costs. The first would require an approved backflow preventer where the cold water line enters the building if any SHW system is connected to the water lines in the building. Two types of SHW system designs will be considered.

*Once-through systems.* These systems can be used as pre-heaters for DHW water heaters. The cold potable water runs through a pipe that enters and exits a solar collector. If the pipe meets the requirements for potable water piping in the IPC, there is no need for backflow protection to prevent contamination of the potable water supply. The existing code language is excessive. Such systems should be exempt from the backflow preventer requirements for solar systems.

*Indirect systems with heat exchangers.* These systems isolate the solar loop fluid from the potable fluid with a heat exchanger. The solar loop fluid can contain propylene glycol, a non-toxic anti-freeze. The heat exchanger “utilizes an essentially nontoxic transfer fluid,” and only a single-wall heat exchanger is required by IPC 608.16.3. This implies that leakage of the solar loop fluid into the house potable water lines is permitted by the IMC. The addition of backflow preventers to isolate the potable water pipes is

redundant and not necessary. If the solar loop fluid is not compatible with potable water, then a double-wall heat exchanger with an atmospheric air gap is required. This is sufficient to prevent contamination of the potable water, and additional backflow preventers should not also be required. To quote a researcher in the active SHW system field, “an approved combination of heat exchangers and heat transfer fluids is sufficient to prevent contamination of potable water.”<sup>194</sup>

There are other possible design features of SHW systems where contamination of the potable water is possible. One is a solid pipe connection where the potable water line refills the solar loop. This can be considered similar to the refill connection to a boiler, which does require a backflow preventer.<sup>195</sup>

A second is where a loop of single-wall potable water pipe is used as a heat exchanger in a solar fluid storage tank. These systems would normally maintain a positive pressure differential between the potable water and the solar loop fluid. Under improbable circumstances, the potable house water could be contaminated. It is not clear how backflow preventers would prevent this. If the potable water lines lost their positive pressure, and the pipe simultaneously developed a leak, solar loop fluid could enter both legs of the potable water line. This requires the installation of a backflow preventer on both the inlet and outlet pipes of the heat exchange loop, which would prevent its normal operation.

The active SHW industry needs to determine under what types of system designs and conditions the contamination of potable water lines is possible. Suitable and effective designs of backflow prevention need to be developed as necessary.

A change in the IRC language could read:

**3402.4.3.1 Exceptions for solar systems that do not require backflow protection.** Solar systems that do not expose potable water to non-potable water are exempt from the requirements of 3402.4.3. This includes solar systems where the potable water acts as the solar loop heat transfer fluid, where the solar loop fluid is essentially non-toxic, and where contamination of the potable water is not possible.

Backflow protection devices need to be installed so they are accessible for inspection and testing. “The frequency of testing shall be determined in accordance with the manufacturer's installation instructions. Where the manufacturer . . . does not specify the frequency of testing, the assembly shall be tested at least annually.”<sup>196</sup> Apparently, “the permit holder shall make the applicable tests. . . .”<sup>197</sup>

There are several other areas of the codes that affect the plumbing aspects of a SHW system, but are not specifically addressed in the chapters on solar systems. Significant code requirements are addressed here.

**Water heater as space heater.** “A water heater used as a part of a space heating system shall have a maximum outlet water temperature of 160°F. The potability of the water shall be maintained throughout the system.”<sup>198</sup> “When a combination water heater-space heating system requires water for space heating at temperatures higher than 140°F, a means such as a mixing valve shall be installed to temper the water for domestic uses.”<sup>199</sup>

**Determining water-supply fixture units and estimating supply demand.** The IRC presents a method for determining the maximum hot-water demand based on the types and numbers of plumbing fixtures and appliances installed in a house.<sup>200, 201</sup> This information can be used to size the piping for the load side of a SHW system. It may also be useful in properly sizing the SHW system components.

**Temperature controls.** “All hot water supply systems shall be equipped with automatic temperature controls capable of adjustments from the lowest to the highest acceptable temperature settings for the intended temperature operating range.”<sup>202</sup> On an active solar system, this will presumably be a tempering valve or similar device.

**Energy cutoff device.** “All automatically controlled water heaters shall be equipped with an energy cutoff device that will cut off the supply of heat energy to the water tank before the temperature in the tank exceeds 210°F.”<sup>203</sup> This type of control will eliminate the flow through SHW collectors when the temperature limit is reached. The 210°F limit may be too high for high elevation locations where the boiling point of water is below 210°F. Language could be added to the IRC to account for the reduction in boiling point due to increased elevation.

**IRC 3301.7 Locations significantly above sea level.** The maximum temperature for the energy cutoff device shall be 2°F below the local boiling point of water.

**Required pan.** If leakage from water heaters or hot-water storage tanks can cause damage, the tank or water heater must be installed in a galvanized steel pan that meets the requirements in IRC 3301.5.1 and 3301.5.2.<sup>204</sup>

**Piping support.** The IPC contains the required piping supports that must be installed for all plumbing systems.<sup>205</sup> This includes the materials, support intervals, and other requirements. Additional requirements exist for supporting plumbing in seismic areas.

**Protection of piping.** Pipes and other plumbing system components must be installed to be protected against corrosion from contact with concrete materials;<sup>206</sup> breakage when passing through or under walls;<sup>207</sup> stress and strain from the expansion, contraction, or settling of other building components;<sup>208</sup> and freezing from being located outside, in unconditioned spaces, or in outside walls.<sup>209</sup> SHW system piping, particularly in retrofits, may need to run through such spaces, particularly attics or unconditioned garages.

**Penetrations between separate dwelling units.** There is a requirement in the IRC for wiring and piping penetrations between dwelling units in a multi-dwelling building. “Penetrations shall be fire resistant rated in accordance with sections 320.1 and 320.2. The through penetration firestop systems tested in accordance with ASTM E 814<sup>210</sup> with a minimum positive pressure differential of 0.01 inch of water. The firestop shall have an ‘F’ rating not less than required for the penetrated assembly.” There are a number of exceptions where this does not apply. These requirements are to prevent the spread of fire from one dwelling unit to an adjacent unit.

**Rodent proofing.** “In or on structures where openings have been made in walls, floors or ceilings, for the passage of pipes, such openings shall be closed and protected by the

installation of approved metal collars that are securely fastened to the adjoining structure.”<sup>211</sup>

**Pipe insulation.** There does not appear to be requirements in any of the reviewed codes for pipe insulation on systems that heat water for domestic use only. There are requirements for the minimum required pipe insulation for HVAC system piping,<sup>212</sup> which would apply to SHW space or space and DHW heating systems.

**Piping.** The pipe and plumbing components associated with a SHW system that contains potable water shall meet the requirements of the IPC.<sup>213</sup> This pipe “shall conform to NSF 6.21<sup>214</sup> and shall conform to one of the standards listed in Table 605.5. All hot water distribution pipe and tubing shall have a minimum pressure rating of 100 psi at 180°F.”<sup>215</sup> The table presents ASTM standards for the following types of allowed pipe:

- Brass pipe
- Chlorinated polyvinyl chloride plastic pipe and tubing
- Copper or copper alloy pipe
- Copper or copper alloy tubing (Type K, WK, L, WL, M, or WM)
- Cross-linked polyethylene plastic tubing
- Cross-linked polyethylene/aluminum/cross-linked polyethylene pipe
- Galvanized steel pipe
- Polybutylene pipe and tubing.

The listed pipe fittings for potable water are included in the following list. These must also be approved for installation with the installed piping material.<sup>216</sup> These must meet the appropriate standards listed in Table 605.6 of the IPC:

- Acrylonitrile butadiene styrene plastic
- Cast iron
- Chlorinated polyvinyl chloride plastic pipe and tubing
- Copper or copper alloy
- Gray iron and ductile iron
- Malleable iron
- Polyethylene plastic
- Polyvinyl chloride plastic
- Steel.

Non-potable piping in hydronic heating systems must meet the requirements of the IMC.<sup>217</sup> The piping standards are the same as for the water distribution piping listed above, except for the following additions and other changes:<sup>218</sup>

- Acrylonitrile butadiene styrene plastic pipe

- Brass tubing
- Chlorinated polyvinyl chloride plastic pipe
- Copper or copper alloy tubing (Type K, L or M)
- Cross-linked polyethylene/aluminum/cross-linked polyethylene pressure pipe
- Lead pipe
- Polyvinyl chloride plastic pipe
- Steel pipe
- Steel tubing.

The materials and standards listed for pipe fittings in hydronic systems include the following:<sup>219</sup>

- Bronze
- Copper and copper alloy
- Gray iron
- Malleable iron
- Plastic
- Steel.

**Solder types.** “Soldered joints shall be made in accordance with the methods of ASTM B 828.<sup>220</sup> . . . The joint shall be soldered with a solder conforming to ASTM B 32.”<sup>221</sup>

**Disinfection of potable water system.** “Water systems shall be purged of deleterious matter and disinfected prior to utilization.”<sup>222</sup> The process includes flushing with clean, potable water and disinfection with a minimum 50 PPM chlorine solution. Local jurisdictions may apply more stringent requirements.

## Electrical Requirements

Electrical components of SHW systems must meet the minimum requirements of the NEC. Typical electrical components include sensors and associated circuits, pumps and their power circuits and controllers, and their power and sensor circuits. The electrical requirements for such components are typical of electrical work in buildings. Applicable NEC Articles will be noted and briefly described.

**Temperature limitation of conductors.** The insulation on electrical wires and cables is temperature rated. “No conductor shall be used in such a manner that its operating temperature will exceed that designated for the type of insulated conductor involved.”<sup>223</sup> This may be a concern for wiring on or adjacent to SHW panels, piping or storage tanks, where the temperatures can get quite high.

**Signal-carrying, low-voltage circuits.** These circuits must comply with the requirements of NEC Article 725 part C, Class 2 and Class 3 Circuits. The cable used for instrumentation signals in dwellings must be rated Type CL2X or CL3X or better.<sup>224</sup>

Cables in ducts delivering environmental air must be rated CL2P or CL3P or better.<sup>225</sup> Other permitted cable types are listed in Table 725-71 of the NEC. Instrumentation wire, Type ITC, is apparently not approved for use in dwellings<sup>226</sup> because of concerns about the fire resistance of the cabling.

There are many requirements regarding the wiring methods used for the signal wiring. The signal-carrying cables cannot be in close contact with power-carrying wires unless one of a number of specific isolation methods is used. These are described in NEC Article 725-54.

**Pump motors.** The fractional horsepower motors typically used in residential SHW systems are considered as “One horsepower or less, automatically started” by the NEC.<sup>227</sup> A motor is considered to be automatically started if its operation is controlled by an electronic controller and not manually. Protection against electric current overload resulting from, for example, a locked pump rotor, must generally be provided by one of the following:

- a separate overload device or circuit breaker, appropriately sized
- a thermal protection mechanism integral to the motor.

**SHW system controllers.** These need to be listed or labeled as appropriate for use in the intended application.<sup>228</sup> This typically requires testing by Underwriter’s Laboratory or a similar organization to be acceptable to local code officials.

#### **4.2.1 Active Solar Hot Water Systems and Systems Analysis of the IECC**

In the IRC, credit for thermal energy from SHW systems is allowed. “Renewable energy shall be permitted to be excluded from the total energy consumption allowed for the building. . . .”<sup>229</sup> This energy must “be derived from a specific collection, storage, and distribution system.”<sup>230</sup> However, there is no mention of RE sources, including heat from SHW systems, in the IECC prescriptive compliance path.<sup>231</sup> The steps necessary to calculate and document the SHW energy credit are generally expensive and complex. It is in the interest of SHW manufacturers and other interest groups to make compliance with the IECC an easier process.

The IECC performance path contains provisions to account for the thermal energy contribution of a SHW system. “Renewable energy shall be permitted to be excluded from the total energy consumption allowed for the building. . . .”<sup>232</sup> This energy must “be derived from a specific collection, storage, and distribution system.”<sup>233</sup> This may exclude SHW systems without storage, including once-through DHW pre-heating designs. A separate definition should be developed for SHW systems, such as:

**IRC 403.1.5 Solar hot water energy exclusion.** Thermal energy from solar hot water systems shall be permitted to be excluded from the total energy consumption allowed for the building. This thermal energy must be used in the building to displace purchased electrical energy, fuel or other thermal energy used for space heating of hot water.

The IECC analysis procedures are designed to calculate envelope thermal loads and resulting HVAC equipment performance.<sup>234</sup> The referenced design methods likewise do

not have provisions for the calculation of SHW system performance, either in general or as applied to a specific building.<sup>235</sup> Building energy simulations like the DOE2 program<sup>236</sup> allow accurate calculation of time varying DHW and space-heating hot water loads. Such programs are not capable of modeling active solar systems. There are programs that allow the performance of active SHW systems to be analyzed,<sup>237</sup> but these are not tied into the calculation methods approved for the IECC analysis path. TRNSYS<sup>238</sup> is a program that does allow the simultaneous analysis of building thermal and hot water loads in conjunction with a coincident hourly analysis of the performance of an SHW system. Unfortunately, TRNSYS is designed as a research tool and is not appropriate or cost-effective for the analysis of each intended SHW installation.

As such, there presently appears to be no practical method to allow credit from SHW-derived thermal energy in either the prescriptive or performance paths in the IECC that is both legal and practical. This could be a major impediment to the implementation of this technology. Consequently, several activities could be undertaken to attack this problem.

- Analysis tools could be developed to allow, as appropriate, prescriptive path compliance in the IECC. These tools could be implemented in maps or tables that relate annual SHW energy performance to collector performance parameters, location, and collector orientation. A prescriptive path analysis tool would likely be adequate for the majority of SHW system installations. It is also likely that such a tool could be easily derived from existing research products from DOE, the SHW industry, and similar sources.
- There is presently no widely used analysis program that integrates SHW system performance with a detailed building simulation. This capability used to be available in the DOE2<sup>239</sup> program and is presently being developed for the Energy-10<sup>240</sup> program. It would also be necessary to develop standard profiles and area-based DHW loads for residential buildings. For the IECC performance path, only a constant value internal gain is specified, which presumably accounts for both electrical and thermal sources.<sup>241</sup> Such a program would allow the simultaneous analysis of a wide number of EE and RE technologies. This program would meet the analysis requirements of the IECC performance path. It would also allow the integration and design optimization of the wide range of these technologies.
- Language needs to be added to IECC Chapters 4 and 5 to allow credit for these proposed analysis methods.

There needs to be a report detailing the proposed design and analysis.<sup>242</sup> If RE is used, it needs to be separately identified from the overall building energy use. Supporting documentation needs to be submitted.

Finally, buildings less than 20,000 ft<sup>2</sup> that derive at least 30% of their annual energy from RE are exempt from a full-year energy system.<sup>243</sup> It is not clear what is meant by this confusing language. This represents a free bonus to some RE technology implementations, as it appears to exempt them from the detailed analysis required in the rest of IECC Chapter 4. However, there is no discussion how this 30% figure is to be calculated, or how compliance with this code is to be established.

### 4.3 Passive Solar Energy and Low-Energy Design

Passive-solar residential-building design involves energy efficiency, solar-oriented glazing, and thermal mass. Low-energy design generally combines passive-solar concepts and low air infiltration with very highly insulated and possibly highly massive buildings. Very low-energy kitchen and other appliances and low-flow water fixtures are often included in passive-solar or other low-energy building designs.

The energy conservation issues of innovative envelopes and glazing are not addressed in this section. These topics are discussed in subsequent sections of this report.<sup>244</sup>

#### 4.3.1 Glazing Area, Orientation, and Shading

There are different compliance issues with the prescriptive and the performance paths.

##### Prescriptive Path

Moving windows to take advantage of passive solar gains changes the glazed fractional area of the various walls. Compliance with any of the four prescriptive requirement sections in the IECC are all affected by this fractional glazed area.

- Compliance by performance on an individual component basis.<sup>245</sup> The overall maximum allowed U-value for each wall, as calculated by a standard one-dimensional parallel path formula, must not exceed the values in IECC Figure 502.2(1). These maximum U-values are a function of the heating-degree-days, with different functions for one and two family dwellings or a building with three or more dwellings. Because windows usually have higher U-values than opaque walls, increasing the glazed fraction on, for example, the south wall requires higher insulation levels for that wall.
- Compliance by total building envelope performance.<sup>246</sup> The U-values for individual components can exceed those required above if the overall heat loss coefficient for the entire building envelope is less than or equal to that for a building with the same geometry that meets the individual component requirements. This allows solar tempering, or the moving of windows to the south side without increasing the building total glazed area, because the total building heat loss coefficient does not change. If the glazed area is increased so that, for example, the south wall does not meet the individual component requirements, the U-value of other components can be modified to bring the entire envelope into compliance.
- Compliance by prescriptive specification on an individual component basis.<sup>247</sup> This alternate path contains minimum insulation R-value compliance requirements for walls and other surfaces based on the building's glazing percent of the total wall area. There are separate tables for a maximum of 8%, 12%, 15%, 18%, 20%, and 25% for one and two dwelling buildings.<sup>248</sup> The requirements for buildings consisting of more than two dwellings are presented in tables for maximum glazing percentages of 20%, 25%, and 30%.<sup>249</sup> All of the tables have minimum insulation R-values based on the heating-degree-days. Values are also presented for the maximum allowed glazing U-value for each glazing percentage and heating degree day. Less work is needed to

determine compliance with this path, because only the window U-values, the percent glazing and the wall, ceiling, floor, basement, slab and crawl-space insulation R-values need to be considered. These tables are only applicable to wood construction.<sup>250</sup> The window area used includes all skylights, above grade windows and basement windows if the basement is conditioned<sup>251</sup>, less one percent.<sup>252</sup> There is no obvious explanation why one percent of this window is excluded. The applicable window area is the rough opening area.<sup>253</sup>

It is likely that these compliance paths are not equivalent for all locations and building designs. A simulation based research effort doing building by DOE or other interested groups could determine the easiest path to take for compliance.

There are restrictions for the solar heat gain coefficient for areas with less than 3500 heating-degree-days. The area-weighted average solar heat gain coefficient for all glazing, including shading effects, must be less than 0.4.<sup>254</sup> The purpose here is to decrease excessive heat gains to reduce cooling loads. However, the impacts on cooling loads are greater for south-or west-facing windows than for other orientations. Directional heat gain coefficient limits may be another area for DOE research.

## Performance Path

The orientation for glazing in the standard design is constrained so that “equal areas on north, northeast, east, southeast, south, southwest, west, and northwest exposures shall be assumed.”<sup>255</sup> This is far from clear in meaning, and there is no explanation if this applies to buildings that do not have walls facing each of these directions. Because this is the basis for the window configuration on the standard design building, it is important to understand what the code means. It likely means that there should be equal glazing areas on walls facing each direction. If this is the case, the wording could be modified to read:

**402.1.3.1.1 Orientation, Standard design.** The standard design shall have equal glazing areas, including glass doors, for walls facing any of the following directions: north, east, south and west.

There is language in the performance path apparently included to allow easier compliance for builders of multiple and essentially identical buildings. If the same design can be built with different orientations (such as in a subdivision) then “Results from shading calculations on a proposed design shall not be used for groups of buildings, unless those results constitute the worst possible building orientation in terms of annual energy use, considering all eight of the above orientations for a group of otherwise identical proposed designs.”<sup>256</sup> However, this language can be confusing if the application is not known. This language could be clearer, as it can be interpreted to affect all performance path analysis where shading is considered. Interested parties should work to replace this language with a clearer explanation of the intended meaning.

Shading from exterior shades, including standard roof overhangs, is not permitted in the standard design.<sup>257</sup> No obvious reason is apparent why these requirements are in the IECC. Generally, this increases the solar gains on glazing and walls and increases the

cooling loads and decreases the heating loads for the standard design. The impact on the total annual energy use by the standard design likely depends on the climate and the design details.

The solar heat gain coefficient in the standard design during the hours of mechanical heating and cooling operation is specified as 0.4 if the heating-degree-days is less than 3500, and 0.68 otherwise.<sup>258</sup> The interior shading multipliers for the standard design are specified as 0.7 in summer and 0.9 in winter.<sup>259</sup> The overall solar heat gain coefficient for the standard design is the product of the two appropriate numbers. There is no definition for “summer” or “winter.” Real values are to be used in the proposed design, if known. Otherwise, values from the IECC Table 102.3(3) are to be used for the exterior solar heat gain coefficient. This Table has solar heat gain coefficient values for single and double glazing with clear, bronze, green and gray glass, metal and nonmetal frames, and operable and fixed panes. Real values are preferable for use in the proposed design, particularly if they result in improved performance relative to the default values or values from the Table.

The performance path has prescriptive requirements that “fixed external or other acceptable shading is provided to limit excessive summer cooling energy gains to the building interior.”<sup>260</sup> This language is inappropriate in the performance path because prescriptive requirements should not be used to defined the requirements of a performance path analysis. All prescriptive requirements in the performance path code sections should be eliminated.

“The exterior door area of the Standard design shall have an equal exterior door area as that of the Proposed design with a U-value of 0.2 Btu/h/ft<sup>2</sup>.”<sup>261</sup> This neglects the possibility of glass doors, or other doors with significant glazed areas. Additional language should be added to clarify this:

**402.1.3.4.3 exception.** Glass doors or the glazed areas of opaque doors shall be treated as fenestration by this chapter of the IECC, and shall meet all requirements for glazing. The opaque areas of the doors shall meet the above requirements.

There are additional prescriptive requirements in the performance path that should be eliminated. The requirements for exclusion from the building annual energy use are defined.<sup>262</sup> “The solar energy passing through windows shall also be considered as qualifying if such windows”<sup>263</sup> meet the criteria of either:

- Have operable insulated shutters that when closed “cause the window area to reduce maximum outward heat flows to those in accordance with Section 502.3.1.”<sup>264</sup> This is an obvious error because Section 502.3.1 refers to the maximum allowable infiltration rates for window and door assemblies. It is not clear which section should be referred to because there are no references in the prescriptive requirements for insulating shades.

or,

- Use at least double pane glass with a low-e layer.<sup>265</sup>

Either option must have the glazing shaded from “direct solar radiation when mechanical cooling is required.”<sup>266</sup> In addition to being inappropriately prescriptive, a literal interpretation of this last requirement requires a movable shade that is smart enough to shade the glazing whenever the cooling system operates.

The entire reference to passive solar in IECC Section 403 Renewable Energy Source Analysis is not needed and redundant. Any analysis tool that qualifies for use in the performance path analysis should be capable of correctly calculating the solar radiation that enters through the windows and the subsequent thermal impact on building components and mechanical systems. The admitted solar gains will be automatically accounted for in the annual energy use numbers. It should be up to the building designer to optimize the proper mix of glazing area, glazing locations, and shading schemes to produce the lowest, or at most the same as the standard design, annual energy loads.

### **4.3.2 Thermal Mass**

Several chapters in the IRC have requirements on the structural aspects of concrete, masonry, and similar building components. The requirements for foundations are in IRC Chapter 4, and concrete floors are in IRC Section 505. Masonry walls are discussed in IRC Sections 604 through 609. There are no requirements in these IRC sections that are obvious impediments to the use of masonry for thermal mass in passive solar buildings.

In seismic zones 3 and 4, anchored masonry and masonry veneer shall be limited to the first story above grade and less than 5 inches in thickness.<sup>267</sup> There is an exception to this constraint allowing the masonry to the second story if the wall framing is braced as per IRC 602.10, Wall bracing.<sup>268</sup>

### **Prescriptive Path**

The prescriptive path gives credit for exterior walls with specified thermal mass by increasing the allowed wall U-value.<sup>269</sup> If the wall thermal mass is at least 6 Btu/ft<sup>2</sup>/°F, IECC Tables 502.1.1(1) through (3) are applicable. The three tables are for exterior insulation, interior insulation, and insulation mixed through the thickness of the wall, as in a log home. The basis for these credits is not clear. There are no different criteria for walls that receive solar gains and those that do not. DOE may be interested in pursuing research into if whether these criteria are reasonable and the appropriate values for the corrections if passive solar energy is considered.

The addition of structural mass to a building may impact the capacity of the heating and cooling systems. In the prescriptive path, “Heating and cooling system design loads for the purpose of sizing systems and equipment shall be determined in accordance with the procedures described in the ASHRAE Handbook of Fundamentals . . .”<sup>270</sup> The procedures in the ASHRAE Handbook of Fundamentals (HOF) are actually a number of procedures. This should be better specified in the IECC. If a building has significant thermal mass, solar radiation through the windows, setback thermostats, and so forth, the

appropriate procedure from the HOF would be an hourly analysis similar to that used to comply with the performance path.

## Performance Path

“Passive solar buildings shall utilize at least 45 Btu/°F of additional thermal mass, per ft<sup>2</sup> of added glass area, when added south-facing glass area exceeds 33 % of the total glass area in walls.”<sup>271</sup> Again, this prescriptive requirement should not be included in the performance path and should be removed. If such language is retained in the performance path, there should be some requirement that the additional mass is exposed to solar radiation. Otherwise, the mass can be completely irrelevant to the effects of the solar radiation.

There are requirements for 8 lb/ft<sup>2</sup> of “Internal mass” and 3.5 lb/ft<sup>2</sup> of “Structural mass,” which are “to be used in calculating annual energy performance.”<sup>272</sup> While not specified, the language implies that the structural mass represents the mass in the building structure for both the standard and proposed designs. There are several problems with this. First, it contradicts the requirements in the previous paragraph for additional thermal mass in some buildings. Second, if the specified level of thermal mass (3.5 lb/ft<sup>2</sup>) is used in both designs, the use of thermal mass in passive solar or other low-energy building designs will not receive credit for the additional mass. Lastly, the requirement of 3.5 lb/ft<sup>2</sup> does not specify per which square foot. It could be per square foot of floor area, glazing, south-facing glazing, wall area, or something else. If the meaning of this section were clear, then language changes could be recommended. However, the ambiguous language and incomplete descriptions here leave many possible interpretations. If prescriptive language is retained in the performance path, then the following language change would be helpful to passive solar designs:

**402.1.3.3 Thermal mass.** The standard design shall have a mass value for furnishings of 8 lb/ft<sup>2</sup> of floor area. The structural mass for the Standard design shall be the actual mass of appropriate lightweight wall construction or other constructions required in this Chapter. The structural mass for the Proposed design shall be the actual mass of the construction in this design.

As previously stated, the addition of thermal mass to a building can impact the required sizes of HVAC equipment. There is no mention in the performance path of equipment sizing. This is significant because if the thermal mass reduced the required equipment sizes, then this equipment would operate at higher part-loads, which means they would operate at higher efficiencies in the proposed design compared to the standard design.

### **4.3.3 High-Efficiency Equipment, Appliances, and Water Use**

There are different compliance issues with the prescriptive and the performance paths.

## Prescriptive Path

There are no requirements in the prescriptive path that constrain the performance of appliances or other equipment to any specified values. There are minimum efficiency requirements for water heating equipment.<sup>273</sup> The plumbing requirements in the IPC restrict the maximum flow rates for various plumbing fixtures.<sup>274</sup> “Shower heads shall have a maximum flow rate of 2.5 gallons per minute at a pressure of 80 pounds per square inch when tested in accordance with ASME A112.18.1.”<sup>275, 276</sup>

## Performance Path

There are no requirements in the IECC performance path for minimum appliance, equipment, or lighting performance.

There is no discussion of the impact of internal gains on building heating and cooling loads in the prescriptive path. If the building loads are calculated according to procedures in the ASHRAE Handbook of Fundamentals,<sup>277</sup> a constant, average sensible load of 1600 Btu/h is specified.<sup>278</sup> There is no schedule specified for hourly variations in this load. More efficient appliances, equipment, lighting, and water use can reduce building energy use. However, there is no language in the IECC that allows these to be factored into the performance path analysis. It can be argued that lights, appliances, and equipment are not part of the building and can often be removed and replaced with less-efficient equipment. This is likely the reason that the IECC performance path specifies a constant 3000 Btu/h internal gain from all sources to be used, apparently for both the standard and proposed designs.<sup>279</sup> Credit for improved efficiency could be accommodated with the following change in the IECC language.

**402.1.3.6.1 Real internal gain levels for the proposed building.** Internal gain levels and schedules based on the actual installed lighting power densities, appliances and number of occupants can be used to comply with the requirements of this chapter. Lighting, appliance, equipment and occupant schedules can be taken from an appropriate source. Occupant related heat gains must be taken from the ASHRAE Handbook of Fundamentals. (Note that an appropriate source is not specified.)

Hot-water heating loads based on the number of dwelling units and the number of bedrooms in each unit are also specified as constant for the standard and proposed designs.<sup>280</sup> There is no specification for hot water heater performance for either the standard or proposed designs in the performance path. Language should be added to correct this deficiency:

**402.1.3.7.1 Water heater efficiency.** The efficiency for the domestic hot water heater for the Standard design shall be found on IECC Table 504.2. The efficiency for the domestic hot water heater for the proposed design shall be the actual efficiency of the proposed equipment.

## *Other Issues*

Overheating is not addressed in the prescriptive path or the performance path. This has been an issue in passive solar designs in the past. Many passive solar designs overheat, causing poor acceptance of this technology. It could be an important design issue, particularly if there are sun-space zones that are not conditioned to reasonable comfort conditions all of the time. Overheating is likely the reason that fixed external shading and maximum glazing solar heat gain coefficients are prescribed in the performance path chapter. However, in addition to the contradiction of prescriptive requirements in the performance path chapter, the prescriptive requirements guarantee neither optimized energy performance nor positively eliminate overheating. If the performance path is followed, most of the analysis tools could also be used to calculate the zone temperatures. This should be the basis for determining the best balance of the various passive solar design elements.

### **4.3.4 Passive Solar Energy, Low-Energy Design, and Systems Analysis of the IECC**

If adequate attention is given to the modeling of glazing orientation and shading, building thermal mass elements, and high efficiency appliances, equipment, and hot water systems, available analysis tools can determine the resulting annual energy impacts. However, the performance path presents constraints or omissions that restrict the accuracy and reasonableness of such analysis. The issues addressed in the previous paragraphs need to be resolved to allow accurate energy credits for the various technologies and design features that were discussed.

## **4.4 Innovative Roof/Attic, Wall Floor, and Foundation Systems**

The innovations considered in this section include roof/attic, wall, floor and foundation components that

- have higher R-value than typical construction. This includes super-insulation construction methods.
- have higher effective thermal mass than typical construction. This includes very heavy mass walls, underground buildings, phase change materials, and Trombe walls.
- increase or decrease solar radiation effects on the building. This includes changing the outside color or emissivity properties and reflective insulation.
- are less expensive than typical construction. This includes construction methods like post and beam and straw bale walls.
- reduce the air infiltration below that of typical construction.

The construction related code implications of each of these areas are considered first. The energy compliance issues are then addressed.

### **4.4.1 General Issues**

The IRC allows any technology, design or method of construction to be used if the local code officials are convinced that they comply with the intent of the provisions of the

code.<sup>281</sup> The following sections explore the envelope technologies in regards to the requirements of the existing codes and suggest code changes or other issues that must be addressed to allow the widespread application of the technologies.

#### **4.4.2 Code Implications of High R-Value Components**

The R-values of building components are increased by the addition of insulation, better insulation, the addition of low-emissivity layers facing air gaps, and the elimination of thermal bridges between conditioned space and the outside. Some of these strategies also include additional structural requirements for the building components.

##### **Additional Thickness of Insulation**

The codes have no restrictions on additional insulation levels beyond that required by the IECC prescriptive path.

##### **Better Insulation**

The codes have no restrictions on the R-value per unit thickness of the insulation. The only requirements in the IECC involve the minimum required insulation levels, either for an entire component assembly, including the framing, or for the cavity insulation alone. Any new and innovative insulation must meet the same requirements for existing products, which are related to fire safety. This includes meeting the flame spread and smoke development requirements in accordance with the ASTM E 84<sup>282</sup> standard.<sup>283</sup> There are exceptions for this requirement if the insulation is in a concealed space and in “substantial contact with the unexposed surface of the ceiling, floor or wall finish.”<sup>284</sup> Exposed attic insulation must “have a critical radiant flux not less than 0.12 W/cm<sup>2</sup>,”<sup>285</sup> when tested in accord with ASTM E 970.<sup>286</sup> This is concerned with preventing ignition of the insulation from radiant heat sources, such as fire.

Presently, the highest commercially available R-value per inch insulation materials are plastic foams. There are requirements specific to foam plastic insulation that are also related to fire safety. This includes meeting the flame spread and smoke development requirements in accordance with the ASTM E 84<sup>287</sup> standard.<sup>288</sup> There are other requirements including separation from interior spaces with thermal barriers,<sup>289</sup> their use with masonry or concrete construction,<sup>290</sup> applications in attics,<sup>291</sup> and their use as an interior finish.<sup>292</sup>

##### **Low-emissivity Insulation Layers**

Reflective insulation and other low-emissivity materials can reduce the radiant heat transfer component in a wall or ceiling assembly and reduce its overall effective U-value. Reflective insulation is typically a metallized plastic film or metal foil. There are no requirements in the codes relative to radiant barriers. Presumably, they must meet fire safety requirements similar to those described above for plastic foam insulation. It should be noted that these products only work if the low-emissivity surfaces are kept clean and installed with an appropriate air gap. If these are installed in direct contact with other materials or allowed to accumulate dust or similarly degraded, the product will

not produce reduced radiant heat transfer. The listed thermal performance for these products should not be allowed unless they are installed according to the manufacturer's installation instructions.<sup>293</sup> However, it is difficult to calculate the thermal effectiveness of these materials as compared to the R-value for typical insulation. "Effective R-value" ratings are needed to aid the implementation and code acceptance for this technology. With such ratings, energy credit for these materials could be calculated for both the prescriptive and performance paths.

## Elimination of Thermal Bridges

Thermal bridges are "short-circuits" of higher conductance materials that penetrate an insulation layer. Typically these are framing elements like wood or metal studs. Structural foam panels eliminate these from many wall or ceiling components. The average thermal transmittance of the gross component area can easily be calculated for these panels and used to determine compliance with the prescriptive path minimum U-values.<sup>294</sup>

## Structural Considerations

Using any of the above strategies may require changes in the structure of components. Structural considerations for wood<sup>295</sup> or metal<sup>296</sup> frame walls are thoroughly covered in the codes. Limitations for wall heights and stud spacing for 2x4 and 2x6 wood<sup>297</sup> and metal<sup>298</sup> walls are presented. Other wall constructions that could be used to allow more thickness for the installation of insulation are not considered. These types of walls, including, for example, staggered 2-by studs that do not bridge the gap between the interior and exterior facings, would presumably need to be individually engineered to satisfy local code officials. Structural foam panels are also not considered in these code sections. These both could be areas of interest for DOE research.

### **4.4.3 Code Implications of High Thermal Mass Components**

Several chapters in the IRC have requirements on the structural aspects of concrete, masonry, and similar building components. The requirements for foundations are in IRC Chapter 4, and concrete floors are in IRC Section 505. Masonry walls are discussed in IRC Sections 604 through 609. There are no requirements in these IRC sections that are obvious impediments to the use of masonry for thermal mass in passive solar buildings.

In seismic zones 3 and 4, anchored masonry and masonry veneer shall be limited to the first story above grade and less than 5 inches in thickness.<sup>299</sup> There is an exception to this constraint allowing the masonry to the second story if the wall framing is braced as per IRC 602.10, Wall bracing.<sup>300</sup>

The requirements for insulating concrete form (ICF) walls are presented in IRC Section 608. These walls are limited to "buildings not greater than 60 feet in plan dimensions, and floors not greater than 32 feet in free span."<sup>301</sup> These should not be serious constraints for most residential construction. "Buildings shall not exceed two stories in height above grade with each story not greater than 10 feet high."<sup>302</sup> The requirements

for ICF walls apply only to “buildings subjected to a maximum design wind speed of 110 mph, a maximum ground snow load of 70 PSF and Seismic zones 0, 1 or 2.”<sup>303</sup> ICF designs that do not meet these constraints must presumably be certified by an accredited design engineer. Other requirements for ICF walls, including material specifications, insulation material and construction details are also presented.<sup>304</sup>

### Adobe, Rammed Earth, and Similar Constructions

These construction techniques are not widely used, but have a historical connection with the RE field. IRC Sections 604 and 605 have the code requirements for adobe brick construction. There are no obvious requirements in these Sections that should be impediments to the use of adobe if conventional unit masonry techniques and materials are followed. Traditional adobe mud may not comply with the requirement that “Mortar for use in masonry construction shall comply with ASTM C 270”<sup>305, 306</sup>

No sections of the codes apply to rammed earth, combinations of cement or asphalt with soil, or similar materials. Local code officials will need to determine compliance with the intent of the provisions of the code. The New Mexico State building code contains language for adobe and rammed earth construction.<sup>307</sup> This could provide a basis for national model codes.

### The Ground as Thermal Mass

Underground and bermed houses use adjacent soil as part of a building’s thermal mass. The external walls in these buildings would likely be considered as foundation walls by code officials for structural purposes. The requirements for foundation walls are in Sections 403 through 406 of the IRC. These walls would need to be insulated to reduce heat loss to the surrounding soil, either to the requirements for exterior walls<sup>308</sup> or foundation walls.<sup>309</sup> These insulation requirements may not be optimal if soil thermal mass is included in the building energy performance. Some scheme where the insulation is placed in the soil, away from the wall, may produce improved performance. It will likely require adequate documentation and possible testing to convince local code officials that schemes like this comply with the intent and purpose of the codes in areas where such design approaches are not widely practiced.

### Trombe Walls

Trombe walls are made of a mass wall with exterior glazing separated by an air gap. The air space may or may not be vented to the interior of the building. Airflow between the air space and the conditioned space may be driven by natural convection or a fan. Code requirements for the mass wall are identical to those previously described.

The glazing must meet the requirements for vertical glazing. Most glazing products in “hazardous locations” must be labeled with the type and thickness of glass.<sup>310</sup> Hazardous locations are those that are subject to breakage by “human impact loads,” or people bumping into them.<sup>311</sup> There are additional labeling requirements for multi-pane window

assemblies.<sup>312</sup> The glazed areas “in hazardous locations . . . shall pass the test requirements of CPSC 16-CFR Part 1201.”<sup>313, 314</sup>

There are specific requirements for the glazing to meet wind and other loads for glass installed within 15 degrees of vertical.<sup>315</sup> These requirements are based on the maximum expected wind and snow loads, glass type, and glazing length and width<sup>316</sup>

The U-values of glazing products “are determined in accordance with NFRC 100 by an accredited, independent testing laboratory.”<sup>317</sup> The products must be labeled by the manufacturer.<sup>318</sup> The solar heat gain coefficient is determined through NFRC 200 by an accredited and independent testing laboratory.<sup>319</sup> The shading coefficient is calculated by dividing the SHGC by 0.87.<sup>320</sup> If these values are not provided by the manufacturer, then default values in IECC Tables 102.3(1), 102.3(2), and 102.3(3) are used for compliance with this code.<sup>321</sup> These values are based on typical commercial products, and high-performance glazing will be penalized if these values are used. For example, there are no low-e windows, triple glazed windows, inert gas fill, or other advanced concepts used for these tables.

The combination of glazing and mass wall in a Trombe wall design may have problems meeting wall U-value requirements and window optical requirements. The glazing is typically selected to admit maximum solar radiation. The mass walls are not typically insulated. Trombe walls may not meet the prescriptive requirements of the IECC and will likely need to the analysis of the performance path to comply.

The air gaps and vents to the inside conditioned spaces may be considered as ducts or plena by code officials. If such, they must meet additional requirements that are primarily designed to reduce the possibility of fire traveling through the ducts. The Code requirements for ductwork are in Chapter 6 of the IMC. There are a number of restrictions that may limit the use of existing wall structures as part of a transpired collector system. For example, stud wall cavities utilized as air plenums shall:

1. “not be utilized as a plenum for supply air . . .
2. not be part of a required fire-resistance-rated assembly . . .
3. not convey air from more than one floor level . . .
4. comply with the floor penetration protection requirements of the building code . . .
5. be isolated from adjacent concealed spaces by approved fire-blocking . . .”<sup>322</sup>

Ducts are required to be constructed of “iron, metal, aluminum or other approved material.”<sup>323</sup> Non-metallic ducts shall be constructed with “Class 0 or Class 1 material in accordance with UL 182.”<sup>324</sup> If the transpired collectors are considered ductwork, the glass covers may not meet these standards.

“Duct system penetrations of walls, floors, ceilings and roofs and air transfer openings in such building components shall be protected as required by the building code.”<sup>325</sup> The IRC has requirements for penetrations of fire-resistant rated wall assemblies, but these apply only to walls separating units in multi-dwelling buildings.<sup>326</sup> Fireblocking in all

residential buildings is required “at openings around . . . ducts at ceiling and floor level, with an approved material to resist the free passage of flame and products of combustion.”<sup>327</sup> The wording of these requirements is not clear, and the developers of the IRC should be contacted for clarification. However, because the codes are always interpreted by local officials, it is reasonable to expect that any ducts that penetrate fire rated assemblies should, at a minimum, have fireblock materials to fill in all openings.

Condensation in Trombe walls may be problematic because they are exposed to ambient air and ambient temperatures. The IMC requires that “provisions shall be made to prevent the formation of condensation on the exterior of any duct.”<sup>328</sup>

#### **4.4.4 Code Implications of Components that Modify Solar Radiation**

This is the use of light or dark paint or other exterior coatings to modify the behavior of the building. Buildings in hot climates are often light colored to reduce cooling loads. It is also possible that selective surfaces or “smart” materials will be developed in the future to improve building performance. There are no restrictions in any of the codes that would limit the application of these strategies and materials. However, local jurisdictions may limit the color choices due to “architectural” considerations.

#### **4.4.5 Code Implications of Less-Expensive Wall Systems**

This includes construction methods like post and beam and straw bale walls. These construction techniques are often sustainable technologies in that they use locally grown and renewable materials. Straw bale construction is used to achieve highly insulated walls. However, many code officials require a separate framing system to support the roof loads in straw bale buildings.<sup>329</sup> Groups supporting the use of straw bale construction are beginning to develop the testing and other requirements to develop appropriate building code language.<sup>330</sup>

The codes do not directly reference either construction technique. However, “the wall construction shall be capable of accommodating all loads imposed according to Section 301 and transmitting the resulting loads to its supporting structural elements.”<sup>331</sup> Post-and-beam construction designs are often unique to each building and will likely require certification from a registered engineer for acceptance by local code officials. If straw bale buildings use an independent frame to support roof loads, then this frame will need to either meet the requirements of IRC Chapter 6 or likewise have an engineering certification. Straw bale buildings without frames will also need this certification or other documentation to convince local officials. In either case, straw bale buildings may need an engineering stamp to show compliance with the deflection under live load<sup>332</sup> and wind loads.<sup>333</sup> Local officials may also need some convincing on the issue of protection from decay and similar problems. The interior surface of the walls need to be covered with gypsum board or a similar material to provide fire resistance.<sup>334</sup> There are also no standards for the determination of U-values for straw bales, either alone or as components of wall assemblies. Development of such standards may be necessary to convince local code officials of the performance of straw bale construction, particularly in areas where it is not common practice.

#### **4.4.6 Code Implications of Components that Reduce Air Infiltration**

The reduction of outside air infiltration reduces both heating and cooling loads. Surprisingly, there do not seem to be any strict requirements for the maximum allowable air infiltration rate for residential buildings in the reviewed codes. However, there are code requirements that are designed to reduce these rates. The maximum allowable air infiltration rates for windows and doors must not exceed the maximum allowed values in IECC Table 502.3.1 when tested in accordance with ASTM E 283.<sup>335</sup> There is a further requirement that “Exterior joints, seams or penetrations in the building envelope, that are sources of air leakage, shall be sealed with durable caulking materials, closed with gasketing systems, taped or covered with moisture vapor-permeable house wrap.”<sup>336</sup> While these requirements will, in general, tend to reduce infiltration rates, their application, particularly that of vapor barriers, is often inadequate or compromised by later construction activities. There are no requirements in the reviewed codes that guarantee a maximum level of infiltration.

A related issue is that of insufficient outside ventilation air. “All habitable rooms shall be provided with aggregate glazing area of not less than 8 percent of the floor area of such rooms. . . . The minimum openable areas to the outdoors shall be 4 percent of the floor area being ventilated.”<sup>337</sup> This glazing need not be operable<sup>338</sup> or can be omitted<sup>339</sup> if mechanical ventilation is provided. The mechanical ventilation must produce 0.35 ACH (air changes per hour) for the ventilated space or 15 CFM (cubic feet per minute) of outside air for each occupant, based on two occupants in the first bedroom and one in each other bedroom.<sup>340</sup> Issues with mechanical ventilation systems will be addressed in a subsequent section of this report. However, it is interesting to note that there is no energy credit given for infiltration/ventilation rates below 0.35 ACH even if heat recovery is applied to the intake and exhaust air streams.

#### **4.4.7 Innovative Roof/Attic, Wall, Floor, and Foundation Systems and Systems Analysis of the IECC**

##### **Components for high R-Value**

There are prescriptive path maximum U-value requirements for all of these components.<sup>341</sup> These are affected by the amount of thermal mass in the wall, the heating-degree-days, and the choice of which prescriptive path to follow.

In the performance path, the wall U-values for the standard design are taken from IECC Table 402.1.1(1). These values are considerably smaller than comparable values used for the prescriptive path compliance if reasonable assumptions for window areas are included. This could be a topic for a small DOE research project. Surprisingly, the performance path analysis does not specify that the real component U-values are to be used in the proposed design. The following language should be added to the code:

**402.1.2.1 Opaque surface U-values.** The real U-values for the opaque surface assemblies shall be used in the proposed design.

If the IECC is amended to include this change, the analysis procedure would allow credit toward compliance for the increased component R-values.

## Components for High Thermal Mass

The IECC prescriptive path allows higher minimum wall U-values if the walls are sufficiently massive.<sup>342</sup> There are separate tables for the U-value modification for insulation on the exterior,<sup>343</sup> interior,<sup>344</sup> and distributed throughout the mass.<sup>345</sup> The equity of this trade-off has not been analyzed for this report. It is likely not equitable for a very massive building. This is an area where research could produce more reasonable algorithms to calculate the allowable reductions in wall U-value. There is no method given to credit mass that is not in the exterior walls, such as masonry floors and interior walls to absorb solar energy. These must be analyzed through the performance path.

“When performing annual energy analyses for buildings with insulated basement or crawl-space walls, the design U-values taken from Table 502.2 for these walls of the standard building shall be permitted to be decreased by accounting for the R-value of the adjacent soil, provided that the foundation wall U-value of the proposed building also accounts for the R-value of the adjacent soil.”<sup>346</sup> Presumably, this allows credit for an advanced design that integrates adjacent soil and an in-soil insulation design for the proposed design and a typical foundation insulation scheme for the standard design. However, there is no discussion of the thermal mass effects of this soil. It would be reasonable to add the following language to this code paragraph:

**402.1.4 Foundation walls.** . . . If the R-value is accounted for in the analysis, the thermal mass effects of the soil shall also be permitted in the analysis of the standard and proposed designs.

The IECC performance path does not allow an accurate accounting for the effects of thermal mass.<sup>347</sup> This can produce inaccurate analysis results and may bias against building designs with high mass components. This is an appropriate area for DOE sponsored research.

The IECC performance path also does not allow an accurate accounting for the effects of Trombe walls. The allowable thermal mass is limited<sup>348</sup> and may not accurately model the real design. Analysis of the air circulation aspects of Trombe walls may be hindered by the limitation to two thermal zones.<sup>349</sup> Many of the analysis tools that would otherwise be suitable for this analysis are not designed or capable of analyzing the thermal performance of Trombe walls.

## Components that Modify Solar Radiation

There are no requirements in the prescriptive or performance paths that restrict or allow the inclusion of these effects. Presumably they are allowed in the present code. Language could be added to explicitly include this effect:

**402.1.2.11 External surface optical characteristics.** The surface solar absorptivity and thermal emissivity for the roof and exterior walls shall be 0.7 and 0.9, respectively, in the Standard design.<sup>350, 351</sup> If known, real surface characteristics shall be used for the Proposed design. Otherwise, the Standard design values shall be used for the Proposed design.

## Less-expensive Wall Systems

Wall systems with mass comparable to standard construction should be reasonably treated in this analysis. High mass components, like adobe walls, will likely not be treated reasonably because of the reasons given above. In any case, the component U-values and other thermal properties need to be developed from sources that are traceable to standard testing methods. For example, the ASHRAE Handbook of Fundamentals does not have the thermal properties for straw or adobe.<sup>352</sup>

## Components that Reduce Air Infiltration

There are no prescriptive path limits for the maximum allowed whole building infiltration rate.

The performance path standard design is determined by a formula from ASHRAE Standard 136.<sup>353, 354</sup> Any reduced infiltration rates claimed for the proposed design must be derived from a post-construction blower-door test. Energy credit for infiltration rates less than 0.35 ACH are not allowed. It is hard to imagine how this requirement can be met if the building fails the blower door test. This test is performed after the building is finished. To significantly reduce the tested ACH value, it may be necessary to remove gypsum board to replace or repair the typically torn vapor barriers. It is likely best to not take credit for the reduced infiltration rates and meet the performance path compliance with the other building components. A second problem with this requirement is that it does not allow credit for air-to-air heat exchangers. The code language should be amended to read:

**402.1.3.10 Air infiltration.** No energy credit shall be granted for ACH levels below 0.35 ACH unless heat recovery is applied to the intake and exhaust air streams. The energy credit is then based on the heat exchanger air flow rate multiplied by its sensible heat recovery effectiveness. If heat recovery or other mechanical ventilation is installed, the infiltration rate shall be zero for all times when the mechanical ventilation is causing positive pressure in the building.

Buildings with a vapor barrier, storm windows or weather-stripped windows, and caulking or sealants on other areas where air could leak in are classified as buildings with “unusually tight construction.”<sup>355</sup> In such buildings, “combustion air shall be obtained from the outdoors. . . .”<sup>356</sup> A large number of requirements for the design and sizing of the natural<sup>357, 358</sup> or forced air<sup>359</sup> ventilation systems apply. This is more stringent than similar requirements in the IRC, which allow indoor air to be used for combustion air in such buildings, if the “room or space has a volume of 50 cubic feet per 1,000 Btu/h input.”<sup>360</sup>

- 
- <sup>35</sup> Wiles, John. 1996. Photovoltaic Power Systems and The National Electrical Code: Suggested Practices. SAND96-2797. Sandia National Laboratories, Albuquerque, NM.
- <sup>36</sup> Ibid., page 19
- <sup>37</sup> NEC, proposed 690-8
- <sup>38</sup> NEC Table 690-31(c)
- <sup>39</sup> Wiles, John. 1996. Photovoltaic Power Systems and The National Electrical Code: Suggested Practices. SAND96-2797. Sandia National Laboratories, Albuquerque, NM.
- <sup>40</sup> NEC 310-12. Conductor Identification
- <sup>41</sup> Wiles, John. 1996. Photovoltaic Power Systems and The National Electrical Code: Suggested Practices. SAND96-2797. Sandia National Laboratories, Albuquerque, NM.
- <sup>42</sup> NEC 690-8. Circuit Sizing and Current
- <sup>43</sup> NEC 690-9(d). DC Rating
- <sup>44</sup> NEC 480-8. Battery Locations
- <sup>45</sup> IRC 301.1 Design
- <sup>46</sup> IRC 301.3 Dead Load
- <sup>47</sup> IRC 301.2.2.4 Weights of Materials
- <sup>48</sup> IRC 802.9.3 Alteration to trusses
- <sup>49</sup> IRC Figure 301.2d. Basic Wind Speed Map
- <sup>50</sup> American Society of Civil Engineers, ASCE 7: Minimum Design Loads for Buildings and Other Structures
- <sup>51</sup> IRC Table 301.2b, Note 6
- <sup>52</sup> AF&PA Wood Frame Construction Manual for One and Two-Family Dwellings, or: SSTD 10 Standard for Hurricane Resistant Residential Construction
- <sup>53</sup> IRC 802.10 Roof tie-down
- <sup>54</sup> IRC 308.5.1 Vertical glass. The data for these calculations are presented in Figures 308.5(1) through 308.5(5)
- <sup>55</sup> IRC 308.5.2 Sloped glazing
- <sup>56</sup> ASTM E 1300 Standard Practice for Determining the Minimum Thickness and Type of Glass Required to Resist a Specified Load
- <sup>57</sup> IRC 301.2 Climatic and geographic design criteria
- <sup>58</sup> IRC 804.3.3 Allowable rafter spans
- <sup>59</sup> IRC Table 804.3.3a Allowable Horizontal Rafter Spans. This refers to the horizontal projection of the spans
- <sup>60</sup> IRC 308.6 Skylights and sloped glazing
- <sup>61</sup> IRC 308.6.1 Definition of skylights and sloped glazing
- <sup>62</sup> IRC 308.6.2 Permitted materials for skylights and sloped glazing
- <sup>63</sup> IRC 202 General Building Definitions
- <sup>64</sup> Consumer Product Safety Commission 16 CFR 1201 Safety Standard for Architectural Glazing

- 
- <sup>65</sup> IRC 308.6.2 Permitted materials for skylights and sloped glazing
- <sup>66</sup> IRC 308.4 Hazardous locations
- <sup>67</sup> Consumer Product Safety Commission 16 CFR 1201. Safety Standard for Architectural Glazing
- <sup>68</sup> IRC 2107.2.7 Roof penetrations
- <sup>69</sup> IRC 903.2.1 Locations
- <sup>70</sup> IRC 905.2.1 Base and cap flashing
- <sup>71</sup> American Society for Testing and Materials E 814 Test Methods for Fire Tests of Through Penetration Fire Stops
- <sup>72</sup> IRC 903.11 Weather Protection, General
- <sup>73</sup> IRC 202 General Building Definitions
- <sup>74</sup> IRC 905.2 Asphalt shingles
- <sup>75</sup> IRC 905.2.2 Slope
- <sup>76</sup> IRC 906 Roof Coverings with Slopes Less than 2 to 12
- <sup>77</sup> IRC 905.2.1 Deck requirements
- <sup>78</sup> IRC 905.2.2 Slope
- <sup>79</sup> American Society for Testing and Materials D 225 Asphalt Shingles Surfaced with Mineral Granules
- <sup>80</sup> American Society for Testing and Materials D 3462 Asphalt Shingles Made from Glass Felt and Surfaced with Mineral Granules
- <sup>81</sup> IRC 905.2.5 Asphalt shingles
- <sup>82</sup> IRC 905.2.3 Underlayment; IRC 905.2.6 Fasteners; IRC 905.2.7 Application; IRC 905.2.8 Underlayment application; IRC 905.2.8.2 Underlayment and high wind; IRC 905.2.9 Flashings
- <sup>83</sup> IRC 904.1 Scope
- <sup>84</sup> IRC 904.2 Compatibility of Materials.
- <sup>85</sup> Underwriter's Laboratory 790 Tests for Fire Resistance of Roof Covering
- <sup>86</sup> IRC 904.3 Material specifications and physical characteristics
- <sup>87</sup> IRC 904.4 Identification
- <sup>88</sup> IRC 905.5 Metal roof shingles
- <sup>89</sup> IRC 906.4 Metal roof panels
- <sup>90</sup> IRC 905.5.4 Material standards
- <sup>91</sup> IRC 906.4.1 Deck requirements
- <sup>92</sup> IRC 906.4.2 Slope
- <sup>93</sup> Ibid.
- <sup>94</sup> IRC 906.4.3 Material standards
- <sup>95</sup> Ibid.
- <sup>96</sup> IRC 909.1 General
- <sup>97</sup> IRC 909.2 Structural and construction loads
- <sup>98</sup> IRC 909.3 Recovering vs. replacement

- 
- <sup>99</sup> IMC 304.8 Guards
- <sup>100</sup> IMC 202 General Definitions
- <sup>101</sup> Ibid.
- <sup>102</sup> IMC 101.2 Scope
- <sup>103</sup> NEC 110-16. Working Space About Electric Equipment (600 Volts, Nominal, or Less)
- <sup>104</sup> Ibid.
- <sup>105</sup> IMC 304.8 Guards
- <sup>106</sup> IMC 306.5 Equipment and appliances on roofs or elevated structures
- <sup>107</sup> IMC 306.6 Sloped roofs
- <sup>108</sup> IRC 301.2.2.5 Height Limitations
- <sup>109</sup> NEC Article 500-1. Scope – Articles 500 Through 505
- <sup>110</sup> NEC Article 500- Hazardous (Classified) Locations
- <sup>111</sup> IRC 908.2 Towers, spires, dome and cupolas
- <sup>112</sup> IECC Section 201 General Definitions
- <sup>113</sup> IECC Chapter 5 Residential Building Design by Component Performance Approach
- <sup>114</sup> IECC 403.1 Renewable Energy Source Analysis – General
- <sup>115</sup> IECC 403.1.1 Solar energy exclusion, one
- <sup>116</sup> IECC 403.2.3 Analysis procedure
- <sup>117</sup> Ibid.
- <sup>118</sup> IECC 402.1.3.6 Internal heat gains (constants)
- <sup>119</sup> IECC 403.2 Documentation
- <sup>120</sup> IECC 402.2.3 Site energy
- <sup>121</sup> IECC 403.2 Documentation, Exception
- <sup>122</sup> Solar Rating and Certification Corporation Document OG-300: Operating Guidelines and Minimum Standards of Certifying Solar Water Heating Systems: An Optional Solar Heating System Certification and Rating Program, April 1997
- <sup>123</sup> IRC 27 Solar Systems
- <sup>124</sup> IMC 304.8 Guards
- <sup>125</sup> IMC 202 General Definitions
- <sup>126</sup> Ibid.
- <sup>127</sup> IMC 101.2 Scope
- <sup>128</sup> IRC 2701.2.1 Access
- <sup>129</sup> IRC 1202 General Mechanical Definitions
- <sup>130</sup> Ibid.
- <sup>131</sup> NEC 110-17 Live Parts Guarded Against Accidental Contact
- <sup>132</sup> IRC 1305.1 Appliance access for inspection service, repair and replacement
- <sup>133</sup> IRC 1202 General Mechanical Definitions

- 
- <sup>134</sup> Ibid.
- <sup>135</sup> IRC 1305.1.2 Equipment in rooms
- <sup>136</sup> IRC 1305.1.3 Equipment in attics
- <sup>137</sup> IMC 304.8 Guards
- <sup>138</sup> IMC 306.5 Equipment and appliances on roofs or elevated structures
- <sup>139</sup> IMC 306.6 Sloped roofs
- <sup>140</sup> IRC 701.2.2 Roof-mounted collectors
- <sup>141</sup> IRC 801.2 Requirements of roof-ceiling construction
- <sup>142</sup> IMC 301.12 Wind resistance
- <sup>143</sup> IRC 903.11 Weather Protection, General
- <sup>144</sup> IRC 202 General Building Definitions
- <sup>145</sup> IRC 904.1 Scope
- <sup>146</sup> IRC 904.2 Compatibility of Materials
- <sup>147</sup> Underwriter's Laboratory 790 Tests for Fire Resistance of Roof Covering
- <sup>148</sup> IRC 904.3 Material specifications and physical characteristics
- <sup>149</sup> IRC 904.4 Identification
- <sup>150</sup> IRC 905.5 Metal roof shingles
- <sup>151</sup> IRC 906.4 Metal roof panels
- <sup>152</sup> IRC 905.5.4 Material standards
- <sup>153</sup> IRC 906.4.1 Deck requirements
- <sup>154</sup> IRC 906.4.2 Slope
- <sup>155</sup> IRC 906.4.3 Material standards
- <sup>156</sup> Ibid.
- <sup>157</sup> IRC 909.1 General
- <sup>158</sup> IRC 909.2 Structural and construction loads
- <sup>159</sup> IRC 909.3 Recovering vs. replacement
- <sup>160</sup> IRC 701.2.2 Roof-mounted collectors
- <sup>161</sup> Underwriter's Laboratory 790 Tests for Fire Resistance of Roof Covering
- <sup>162</sup> IMC 502.3.1 Collectors mounted above the roof. Exception
- <sup>163</sup> IRC 906.6.2 Materials standards. These refer to the Rubber Manufacturer's Association standards RP-1, RP-2 and RP-3
- <sup>164</sup> IRC 906.7.2
- <sup>165</sup> IRC 906.8.2
- <sup>166</sup> IRC 906.9.2
- <sup>167</sup> IRC 27.2.3 Pressure and temperature relief
- <sup>168</sup> IPC 504.5 Relief valve approval

- 
- <sup>169</sup> IPC 504.7.1,2 and 3 Relief outlet waste discharge, location and materials
- <sup>170</sup> IPC 2701.2.4 Vacuum relief
- <sup>171</sup> IMC 1502.4.2 Vacuum
- <sup>172</sup> IRC 2701.2.5 Protection from freezing
- <sup>173</sup> IPC 305.6 Freezing
- <sup>174</sup> IRC 27.2.6 Expansion tanks. Refers to IRC section 2303
- <sup>175</sup> IRC 2302.2 Minimum capacity
- <sup>176</sup> IRC 2302.1 General
- <sup>177</sup> IMC 1009.3 Open-type expansion tanks
- <sup>178</sup> IRC 2701.3.1 Collectors
- <sup>179</sup> IRC 202 General building definitions
- <sup>180</sup> Jay Burch, NREL. Personal conversation
- <sup>181</sup> IRC 2701.3.2 Thermal storage units
- <sup>182</sup> IPC 505.1 Unfired vessel insulation
- <sup>183</sup> IECC 504.2 Water heaters, storage tanks and boilers
- <sup>184</sup> IRC 2701.4 Prohibited heat transfer fluids
- <sup>185</sup> IMC 202 General definitions
- <sup>186</sup> Ibid.
- <sup>187</sup> IMC 1503.1 Flash point
- <sup>188</sup> IMC 1501.2 Potable water supply
- <sup>189</sup> IPC 202 General definitions
- <sup>190</sup> American Society of Sanitary Engineering 1012 Vacuum Breakers
- <sup>191</sup> American Society of Sanitary Engineering 1013 Performance Requirements for Reduced Pressure Principle Backflow Preventers
- <sup>192</sup> IRC 3402.4.3 Solar systems
- <sup>193</sup> IPC 608.16.3 Heat exchangers
- <sup>194</sup> Jay Burch, NREL. Personal conversation
- <sup>195</sup> IPC 608.16.2 Connections to boilers
- <sup>196</sup> IPC 312.9 Inspection and testing of backflow prevention assemblies
- <sup>197</sup> IPC 312.1 Required tests
- <sup>198</sup> IPC 501.2 Water heater as space heater
- <sup>199</sup> IRC 3302.2 Scald protection
- <sup>200</sup> IRC 3403.5 Determining water-supply fixture units
- <sup>201</sup> IRC 3403.6 Estimating supply demand
- <sup>202</sup> IPC 501.8 Temperature controls
- <sup>203</sup> IRC 3301.7 Energy cutoff device.

- 
- <sup>204</sup> IRC 3301.5 Required pan
- <sup>205</sup> IPC 308 Piping support
- <sup>206</sup> IPC 305.1 Corrosion
- <sup>207</sup> IPC 305.2 Breakage
- <sup>208</sup> IPC 305.3 Stress and strain
- <sup>209</sup> IPC 305 Protection of pipes and plumbing system components
- <sup>210</sup> American Society for Testing and Materials E 814 Test Methods for Fire Tests of Through Penetration Fire Stops
- <sup>211</sup> IPC 304.4 Rodent proofing
- <sup>212</sup> IECC 503.3.3.1 Piping insulation
- <sup>213</sup> IPC 605.5 Water distribution pipe
- <sup>214</sup> National Sanitation Foundation 61 Drinking Water System Components – Health Effects
- <sup>215</sup> Ibid.
- <sup>216</sup> IPC 605.6 Fittings
- <sup>217</sup> IMC 1202.4 Piping materials standards
- <sup>218</sup> IMC Table 1202.4 Hydronic Pipe
- <sup>219</sup> IMC Table 1202.5 Hydronic Pipe Fittings
- <sup>220</sup> American Society for Testing and Materials B 828 – 92 Practice for Making Capillary Joints by Soldering of Copper and Copper Alloy Tube and Fittings
- <sup>221</sup> American Society for Testing and Materials B 32 – 94 Specification for Solder Metal
- <sup>222</sup> IPC 610 Disinfection of potable water system
- <sup>223</sup> NEC 310-10. Temperature limitations of conductors
- <sup>224</sup> NEC 725-71(c) Types CL2X and CL3X
- <sup>225</sup> NEC 725-61(a) Plenum
- <sup>226</sup> NEC 727-2 Uses permitted
- <sup>227</sup> NEC 430-32(c) Continuous-duty motors. One horsepower or less, automatically started
- <sup>228</sup> NEC 90-7 Examination of equipment for safety
- <sup>229</sup> IECC 403.1 Renewable Energy Source Analysis – General
- <sup>230</sup> IECC 403.1.1 Solar energy exclusion, one
- <sup>231</sup> IECC Chapter 5 Residential Building Design by Component Performance Approach
- <sup>232</sup> IECC 403.1 Renewable Energy Source Analysis – General
- <sup>233</sup> IECC 403.1.1 Solar energy exclusion, one
- <sup>234</sup> IECC 403.2.3 Analysis procedure
- <sup>235</sup> Ibid.
- <sup>236</sup> DOE2
- <sup>237</sup> Beckman, W. and Duffie, J. 1977. Solar heating design by the f-Chart method

- 
- <sup>238</sup> Klein, S., and Beckman, W. 1994. TRNSYS: A transient simulation program. Engineering Experiment Station Report 38-14. University of Wisconsin, Madison
- <sup>239</sup> Lawrence Berkeley Laboratory. 1982. DOE2 Engineers Manual. Lawrence Berkeley Laboratory Report LBL-11353. National Technical Information Services, Springfield, VA
- <sup>240</sup> Balcomb, J. D. 2001.
- <sup>241</sup> IECC 402.1.3.6 Internal heat gains (constants)
- <sup>242</sup> IECC 403.2 Documentation
- <sup>243</sup> IECC 403.2 Documentation, Exception
- <sup>244</sup> Innovative Roof/Attic, Wall, Floor, and Foundation Systems and Innovative Fenestration Systems or Products sections of this report.
- <sup>245</sup> IECC 502.2.1 Compliance by performance on an individual basis.
- <sup>246</sup> IECC 502.2.2 Compliance by total building envelope performance.
- <sup>247</sup> IECC 502.2.4 Compliance by prescriptive specification on an individual component basis.
- <sup>248</sup> IECC Tables 502.2.4(1) through (6).
- <sup>249</sup> IECC Tables 502.2.4(7) through (9).
- <sup>250</sup> IECC 502.2.4.2 Wood construction only.
- <sup>251</sup> IECC 502.2.4.3 Window area.
- <sup>252</sup> IECC 502.2.4.4 Window area, exempt.
- <sup>253</sup> IECC 502.2.4.3 Window area.
- <sup>254</sup> IECC 502.4 Fenestration solar heat gain coefficient.
- <sup>255</sup> IECC 402.1.3.1.1 Orientation, Standard design.
- <sup>256</sup> IECC 402.1.3.1.2 Shading calculations, Proposed design.
- <sup>257</sup> IECC 402.1.3.1.3 Exterior shading, Standard design.
- <sup>258</sup> IECC 402.1.3.1.4 Fenestration system solar heat gain coefficient, Standard design.
- <sup>259</sup> IECC 402.1.3.1.5 Interior shading, Standard design and Proposed design.
- <sup>260</sup> IECC 402.1.3.2 Passive solar.
- <sup>261</sup> IECC 402.1.3.4.3 Doors.
- <sup>262</sup> IECC 403.1 General.
- <sup>263</sup> Ibid.
- <sup>264</sup> IECC 403.1.1.1 Insulated shutters.
- <sup>265</sup> IECC 403.1.2.1 Insulated glass.
- <sup>266</sup> IECC 403.1.1.2 or 403.1.2.2 Shading.
- <sup>267</sup> IRC 301.2.2.2 Anchored stone and masonry veneer.
- <sup>268</sup> IRC 301.2.2.2 Anchored stone and masonry veneer, Exception.
- <sup>269</sup> IECC 502.1.1 Thermal capacity.
- <sup>270</sup> IRC 503.3.1 Load calculations.
- <sup>271</sup> IECC 402.1.3.3 Heat storage (thermal mass).

- 
- <sup>272</sup> Ibid.
- <sup>273</sup> IECC 504.2.1 Performance efficiency.
- <sup>274</sup> IPC 604.4 Maximum flow and water consumption.
- <sup>275</sup> American Society of Mechanical Engineers A112.18.1M - 94 Plumbing Fixture Fittings – with 1995 Errata
- <sup>276</sup> IECC 504.8.1 Showers
- <sup>277</sup> IRC 503.3.1 Load calculations.
- <sup>278</sup> ASHRAE Handbook of Fundamentals, 27.4.
- <sup>279</sup> IECC 402.1.3.6 Internal heat gains.
- <sup>280</sup> IECC 402.1.3.7 Domestic hot water.
- <sup>281</sup> IRC 104.11 Alternative materials, design and methods of construction and equipment.
- <sup>282</sup> American Society for Testing and Materials E 84. Test Method for Surface Burning Characteristics of Building Materials.
- <sup>283</sup> IRC 319.1 Insulation.
- <sup>284</sup> IRC 319.1 Exception 1.
- <sup>285</sup> IRC 319.4 Exposed attic insulation.
- <sup>286</sup> American Society for Testing and Materials E 970. Standard Test Method for Critical Radiant Flux of Exposed Attic Floor Insulation Using a Radiant Heat Energy Source.
- <sup>287</sup> American Society for Testing and Materials E 84. Test Method for Surface Burning Characteristics of Building Materials.
- <sup>288</sup> IRC 317.1 Surface burning characteristics.
- <sup>289</sup> IRC 317.2 Thermal barrier.
- <sup>290</sup> IRC 317.2.1 Masonry or concrete construction.
- <sup>291</sup> IRC 317.2.3 Attics.
- <sup>292</sup> IRC 317.4 Interior finish.
- <sup>293</sup> IECC 102.4 Materials, systems and equipment installation.
- <sup>294</sup> IECC 502.2.1.1 Walls.
- <sup>295</sup> IRC Section 602.
- <sup>296</sup> IRC Section 603.
- <sup>297</sup> IRC 602.3.1 Stud spacing.
- <sup>298</sup> IRC 603.3.2 Load-bearing walls.
- <sup>299</sup> IRC 301.2.2.2 Anchored stone and masonry veneer.
- <sup>300</sup> IRC 301.2.2.2 Anchored stone and masonry veneer, Exception.
- <sup>301</sup> IRC 608.2 Applicability limits.
- <sup>302</sup> Ibid.
- <sup>303</sup> Ibid.
- <sup>304</sup> IRC 608.3 through 608.9.

- 
- <sup>305</sup> American Society for Testing and Materials C 270. Specification for Mortar for Unit Masonry.
- <sup>306</sup> IRC 605.1 Mortar.
- <sup>307</sup> Ron Judkoff, NREL. Personal conversation.
- <sup>308</sup> IECC 502.2.1.1 Walls.
- <sup>309</sup> IECC 502.2.1.6 Basement walls, for example.
- <sup>310</sup> IRC 308.1 Identification.
- <sup>311</sup> IRC 308.4 Hazardous locations.
- <sup>312</sup> IRC 308.1.1 Identification of multipane assemblies.
- <sup>313</sup> Consumer Product Safety Commission 16 CFR 1201. Safety Standard for Architectural Glazing.
- <sup>314</sup> IRC 308.3 Human impact loads.
- <sup>315</sup> IRC 308.5.1 Vertical glass.
- <sup>316</sup> Ibid.
- <sup>317</sup> IECC 102.3 Fenestration product rating, certification and labeling.
- <sup>318</sup> Ibid.
- <sup>319</sup> Ibid.
- <sup>320</sup> Ibid.
- <sup>321</sup> Ibid.
- <sup>322</sup> IMC 602.3 Stud cavity and joist space plenums.
- <sup>323</sup> IMC 603.3 Metallic ducts.
- <sup>324</sup> IMC 603.4 Nonmetallic ducts.
- <sup>325</sup> IMC 603.6 Rigid duct penetrations.
- <sup>326</sup> IRC 320.4 Penetrations.
- <sup>327</sup> IRC 602.8 Fireblocking required.
- <sup>328</sup> IMC 603.11 Condensation.
- <sup>329</sup> Swentzell Steen, Athena; Steen, Bill; Bainbridge, David; Eisenberg, David; “The Straw Bale House,” Pages 9 through 12, 1994.
- <sup>330</sup> Ibid.
- <sup>331</sup> IRC 601.2 Requirements.
- <sup>332</sup> IRC 301.6 Deflection.
- <sup>333</sup> IRC 301.2.1.1 Design criteria
- <sup>334</sup> IRC 702.1 General.
- <sup>335</sup> American Society for Testing and Materials E 283. Standard Method of Test for Rate of Air Leakage Through Exterior Windows, Curtain Walls and Doors.
- <sup>336</sup> IECC 502.3.2 Caulking and sealants.
- <sup>337</sup> IRC 303.1 Habitable rooms.
- <sup>338</sup> Ibid., Exception 1.
- <sup>339</sup> Ibid., Exception 2.

- 
- <sup>340</sup> Ibid.
- <sup>341</sup> IECC 502.2.1.1 Walls, for example.
- <sup>342</sup> IECC 502.1.1 Thermal capacity.
- <sup>343</sup> IECC Table 502.1.1(1) Required  $U_w$  for wall insulation with a heat capacity equal to or exceeding 6 Btu/ft<sup>2</sup>/°F with insulation placed on the exterior of the wall mass.
- <sup>344</sup> IECC Table 502.1.1(2) Required  $U_w$  for wall insulation with a heat capacity equal to or exceeding 6 Btu/ft<sup>2</sup>/°F with insulation placed on the interior of the wall mass.
- <sup>345</sup> IECC Table 502.1.1(3) Required  $U_w$  for wall insulation with a heat capacity equal to or exceeding 6 Btu/ft<sup>2</sup>/°F with integral insulation.
- <sup>346</sup> IECC 402.1.4 Foundation walls.
- <sup>347</sup> IECC 402.1.3.3 Heat Storage (thermal mass).
- <sup>348</sup> Ibid.
- <sup>349</sup> 402.1.3.5 Heating and Cooling Controls.
- <sup>350</sup> These values are used as the defaults in the DOE2.1E program. They are representative of a wide range of painted and other types of surfaces.
- <sup>351</sup> Winkleman, F., et. al. 1993. DOE-2 BDL Summary. Lawrence Berkeley Laboratory.
- <sup>352</sup> ASHRAE Handbook of Fundamentals, Chapter 24, 1997.
- <sup>353</sup> ASHRAE 136. Method of Determining Air Change Rates in Detached Buildings.
- <sup>354</sup> IECC 402.1.3.10 Air infiltration.
- <sup>355</sup> IMC 202 General definitions.
- <sup>356</sup> IMC 702.1 Air from the same room or space.
- <sup>357</sup> IMC 703.1 Outdoor Air (Condition 1).
- <sup>358</sup> IMC 703.1 Outdoor Air (Condition 2).
- <sup>359</sup> IMC 707 Forced Combustion Supply Air.
- <sup>360</sup> IRC 2001.1 Buildings of unusually tight construction.

## 4.5 Innovative Fenestration Systems or Products

Innovative fenestration systems or products include glazing with improved thermal resistance, improved or application tailored optical properties, and a variety of possible technologies that change the thermal or optical properties.

Any innovative glazing products must meet the minimum requirements for windows and similar products. “Windows shall be tested and certified to indicate compliance with the requirements of the following specification:

AAMA 101<sup>361</sup> / NWWDA I.S. 2<sup>362</sup>  
Polyvinyl Chloride. ASTM D 4099<sup>363, 364</sup>

Sliding glass doors are also subject to the same requirements.<sup>365</sup> These requirements are waived for “fixed glazed openings constructed on-site and decorative glazing.”<sup>366</sup> Glass door panels used as fixed windows are not specifically addressed, but will likely be viewed as windows by the code officials.

The minimum requirements for the glazed area are “All habitable rooms shall be provided with aggregate glazing area of not less than 8% of the floor area of such rooms.” There are separate requirements for windows in sleeping rooms where the windows also provide egress in case of fire.<sup>367</sup> The glazing can be omitted in rooms if egress is not required and mechanical ventilation is provided for that space.<sup>368</sup>

Most glazing products in “hazardous locations” must be labeled with the type and thickness of glass.<sup>369</sup> Hazardous locations are those that are subject to breakage by “human impact loads,” or people bumping into them.<sup>370</sup> There are additional labeling requirements for multi pane window assemblies.<sup>371</sup> The glazed areas “in hazardous locations . . . shall pass the test requirements of CPSC 16-CFR Part 1201.”<sup>372, 373</sup>

There are specific requirements for the glazing to meet wind and other loads for glass installed within 15 degrees of vertical,<sup>374</sup> and glass installed at more than 15 degrees from vertical.<sup>375</sup> These requirements are based on the maximum expected wind and snow loads, glass type, glazing length and width and slope.<sup>376</sup> There is no list of materials approved for use for this glazing. However, for skylights, the permitted glazing materials include “Approved rigid plastics.”<sup>377</sup> There is no list of “Approved rigid plastics.” This would likely also pertain to the use of plastics for window applications.

The U-values of glazing products “are determined in accordance with NFRC 100 by an accredited, independent testing laboratory.”<sup>378</sup> The products must be labeled by the manufacturer.<sup>379</sup> The solar heat gain coefficient is determined through NFRC 200 by an accredited and independent testing laboratory.<sup>380</sup> The shading coefficient is calculated by dividing the SHGC by 0.87.<sup>381</sup> If these values are not provided by the manufacturer, then default values in IECC Tables 102.3(1), 102.3(2), and 102.3(3) are used for compliance with this code.<sup>382</sup> These values are based on typical commercial products, and high performance glazing will be penalized if these values are used. For example, there are no

low-e windows, triple-glazed windows, inert gas fill, or other advanced concepts used for these tables.

#### **4.5.1 Innovative Fenestration Systems or Products and Systems Analysis of the IECC**

##### **Prescriptive Path**

The U-values for glazing systems is included in the calculation of the wall U-values for the various optional compliance routes through the prescriptive path.<sup>383</sup>

The allowable air infiltration rates for windows are presented in IECC Table 502.3.1.<sup>384</sup> Any glazing U-value improvements can allow compensating reductions in the requirements for the wall or other building components.<sup>385</sup> Similarly, skylight U-values are used to calculate the overall U-value for roofs.<sup>386</sup> If the chosen compliance path is “by prescriptive specification on an individual component basis,”<sup>387</sup> the glazing must not exceed a specified U-value, but no additional credit is derived for improved performance.

In the prescriptive path, for “locations with heating-degree-days less than 3,500, the combined solar heat gain coefficient (the area weighted-average) of all glazed fenestration products (including the effects of any permanent exterior solar shading devices) in the building shall not exceed 0.4.”<sup>388</sup> The purpose here is to reduce heat gains during cooling periods. It is not clear how code officials might interpret this in regards to switchable glazing or other possible controllable glazing strategies. There is no consideration in the prescriptive path given to other methods of reducing excessive solar gains, including exterior or interior shading. The solar heat gain coefficients also do not consider the variations in solar climates found in different locations. The entire area of optimizing glazing and shading designs for passive solar performance and prevention of overheating could be a DOE research project. Guidelines for designs appropriate for different locations could be developed.

##### **Performance Path**

The requirements for glazing area, orientation and shading, and solar heat gain coefficients for the standard design glazing are discussed in the previous section on passive solar. The glazing air-to-air U-values for the standard design are specified in the IECC Table 402.1.1(2). These values are for the entire assembly, including the framing.

The discussion for the proposed design glazing orientation and shading for passive solar also applies here. The real solar heat gain coefficients for the proposed design glazing can be used in the energy analysis.<sup>389</sup> “The same schedule of interior shading values, expressed as the fraction of the solar heat gain admitted by the fenestration system that is also admitted by the interior shading, shall be assumed for the standard and proposed design.”<sup>390</sup> This is inappropriate for a number of potential fenestration technologies. Interior shades for windows with low visible transmissivity will be used less often than for typical windows. Automatically controlled interior shades could be designed to react to the admitted sunlight levels. On a residential application, these are likely to have a

different “schedule” than those under manual control. Finally, switchable glazing strategies can be designed to control the admitted sunlight without the need for interior shades. Such glazing could be developed to have stepped or continuously variable shading. All of these strategies result in significantly different solar gains levels over time than manually operated shades. The present code requirements do not give adequate credit to the energy impacts of such schemes. The following language could be added to help remedy this problem.

**402.1.3.1.5 Interior shading, Standard design and Proposed design.**

**Exception 2.** If the Proposed design has windows or controlled shading systems that produce significantly different shading behavior than typical windows and shades, the real shading behavior can be used in the proposed design energy model.

There is no direct discussion of the U-value to use for the glazing in the proposed design. However, because the solar heat gain coefficient can be used, presumably the real U-value is also appropriate. This should give adequate credit to glazing with lower U-values.

The advanced concepts in improved glazing, particularly the modification of the thermal or optical properties in response to temperature, light levels, or other time-changing environmental parameters is not available in many energy analysis tools that would otherwise qualify for use in the performance path. These tools should be reviewed and rated as to their appropriate application to these technologies.

## **4.5.2 Sunspaces**

Sunspace additions can meet the energy requirements of the IECC by either meeting the prescriptive requirements of Chapter 5, the performance path requirements of Chapter 4, or, if under 500 ft<sup>2</sup>, special prescriptive requirements in Chapter 1.<sup>391</sup> The latter requires components complying with the requirements of IECC Table 101.4.2.4.<sup>392</sup> Additionally, the total fenestration area must be less than the gross wall and roof areas.<sup>393</sup> If the fenestration area exceeds 40%, then compliance must be through either the normal IECC prescriptive or performance paths.

---

<sup>361</sup> American Architectural Manufacturers Association. Voluntary Specifications for Aluminum Prime Windows and Sliding Glass Doors.

<sup>362</sup> National Wood Window & Door Association. Industry Standard for Wood Window Units.

<sup>363</sup> American Society for Testing and Materials. Standard Specification for Poly Vinyl Chloride Prime Windows.

<sup>364</sup> IRC 6010.1 Testing and certification.

<sup>365</sup> IRC 611.1 Testing and certification.

<sup>366</sup> IRC 6010.1 Testing and certification.

<sup>367</sup> IRC 310.1 Emergency escape required.

- 
- <sup>368</sup> IRC 303.1 Habitable rooms. Exception 2.
- <sup>369</sup> IRC 308.1 Identification.
- <sup>370</sup> IRC 308.4 Hazardous locations.
- <sup>371</sup> IRC 308.1.1 Identification of multipane assemblies.
- <sup>372</sup> Consumer Product Safety Commission 16 CFR 1201. Safety Standard for Architectural Glazing.
- <sup>373</sup> IRC 308.3 Human impact loads.
- <sup>374</sup> IRC 308.5.1 Vertical glass.
- <sup>375</sup> IRC 308.5.2 Sloped glazing.
- <sup>376</sup> Ibid.
- <sup>377</sup> IRC 308.6.2 Permitted materials for skylights and sloped glazing.
- <sup>378</sup> IECC 102.3 Fenestration product rating, certification and labeling.
- <sup>379</sup> Ibid.
- <sup>380</sup> Ibid.
- <sup>381</sup> Ibid.
- <sup>382</sup> Ibid.
- <sup>383</sup> IECC 502.2.1.1 Walls, for example.
- <sup>384</sup> IECC 502.3.1 Window and door assemblies.
- <sup>385</sup> Ibid.
- <sup>386</sup> IECC 502.2.1.2 Roof/ceiling, for example.
- <sup>387</sup> IECC 502.2.4 Compliance by prescriptive specification on an individual component basis.
- <sup>388</sup> IECC 502.4 Fenestration solar heat gain coefficient.
- <sup>389</sup> IECC 402.1.3.1.4 Fenestration system solar heat gain coefficient, Standard design.
- <sup>390</sup> IECC 402.1.3.1.5 Interior shading, Standard design and Proposed design.
- <sup>391</sup> IECC 101.4.2.4 Prescriptive path for additions and window replacements.
- <sup>392</sup> IECC Table 101.4.2.4 Prescriptive envelope component criteria additions to and replacement windows for existing single-family residential buildings.
- <sup>393</sup> IECC 101.4.2.4 Prescriptive path for additions and window replacements.

## 4.6 Innovative Heating, Ventilation and Air Conditioning (HVAC) Systems

A wide range of potential innovations is possible in HVAC systems, including the adaptation of commercial system technologies to residential applications. The technologies considered here include the following:

1. Higher efficiency equipment
2. Equipment with part-load curves tailored to real-world load histograms
3. Improved control strategies, including smart or adaptive controls
4. Variable speed fans or pumps
5. High efficiency motors
6. Mechanical ventilation
  - Air-to-air heat exchangers
  - Economizers
  - CO<sub>2</sub> sensor control for ventilation air
7. Evaporative cooling
  - Direct – Swamp coolers
  - Indirect
  - Direct/indirect
  - Evaporative cooling of condensers / cooling towers
  - Water side economizers and strainer cycles
8. Multiple zoning in buildings
9. Ground source heat pumps
10. Gas cooling including engine driven heat pumps and absorption cooling.

This list does not include all of the potential residential HVAC technologies for the present and the future. However, a discussion of the code implications of the above technologies likely addresses most of the relevant issues for other technologies.

General requirements in the codes apply to all HVAC equipment. “All appliances and equipment installed in mechanical systems covered by this code shall be listed and bear the label of an approved agency or shall be approved by the building officials for safe use.”<sup>394</sup> Access and clearance must be provided “to permit cleaning of heating and cooling surfaces, replacement of filters, blowers, motors, controls, vent connections, lubrication of moving parts, and adjustments.”<sup>395</sup> There are special requirements for installations in attics,<sup>396</sup> crawl spaces,<sup>397</sup> or outside the building.<sup>398</sup> Heat-producing appliances need to meet specified clearance requirements.<sup>399</sup>

“Heating and cooling equipment shall be sized according to ACCA Manual J.”<sup>400, 401</sup> These sizing requirements should be reviewed, particularly in regards to buildings with high thermal mass, setbacks, or other control strategies that may impact the real peak HVAC loads that must be satisfied. Oversizing of HVAC equipment is typical in residential construction. This leads to equipment operating at low part loads most of the time, with a resulting loss in annual average efficiency. A study analyzing the degree of oversizing that is typically found in real installations, and the energy implications of this practice would be a reasonable research project for DOE to pursue.

All heating and cooling equipment must be installed to meet the requirements of the NEC, IPC, IMC, and IFGC for all such equipment. This should present no hardship, as it includes current general practice in the various building trades. There are also particular requirements that may be applicable as a result of the characteristics of these technologies and for low-energy buildings in general.

Buildings with a vapor barrier, storm windows or weather-stripped windows, and caulking or sealants on other areas where air could leak in are classified as buildings with “unusually tight construction.”<sup>402</sup> In such buildings, “combustion air shall be obtained from the outdoors . . . .”<sup>403</sup> A large number of requirements for the design and sizing of the natural<sup>404, 405</sup> or forced-air<sup>406</sup> ventilation systems apply. This is more stringent than similar requirements in the IRC, which allow indoor air to be used for combustion air in such buildings, if the “room or space has a volume of 50 cubic feet per 1,000 Btu/h input.”<sup>407</sup>

The issues are now addressed as applied to the HVAC technologies listed above.

#### **4.6.1 Improved Efficiency**

There are certainly no restrictions on using HVAC equipment that exceeds the minimum efficiency requirements in the IECC<sup>408</sup> and other codes. Potential issues with meeting these performance requirements are discussed in the next section.

#### **4.6.2 Equipment with Part-Load Curves Tailored to Real-World Load Histograms**

Buildings infrequently face design conditions, and HVAC equipment usually operates at less than full capacity. Analysis of hundreds of buildings indicates that most of the time, the HVAC equipment typically operates at less than 50% of capacity.<sup>409</sup> Traditionally, HVAC designers and test standards have been more interested in meeting the peak loads than in optimizing energy consumption over time. Equipment is entering the commercial-scale HVAC market that addresses this problem and provides much improved part-load efficiencies compared to previously available equipment. It is reasonable to expect similar concepts to enter the residential HVAC market. An example of such equipment would use variable-speed motors on air-conditioner compressors.

The minimum performance for HVAC cooling and heating equipment is specified in the codes as integrated typical performance factors. These include the Annual Fuel Utilization Efficiency (AFUE) for furnaces, Heating Seasonal Performance Factor (HSPF) for heat pump heating and the Seasonal Energy Efficiency Ratio (SEER) for air conditioners and chillers.<sup>410, 411</sup> These performance factors are calculated with assumptions on the fraction of each year the equipment operates at a series of part-load values. Innovative heating or cooling equipment could operate at high part-load efficiency levels. For example, they will not cycle on and off like a lightly loaded air conditioner, but would run continuously at a lower cooling energy output. The differences in the assumed part-load performance from the assumptions for the integrated

performance factors and innovative equipment may bias against such equipment. An addition to the IECC minimum equipment efficiency requirements could read:

**503.2.2 Exception for equipment with improved part-load energy efficiency.**

Heating and cooling equipment designed for improved part-load EE shall comply with this code if testing to appropriate standards (or recognized engineering analysis) shows annual performance equal to or higher than the appropriate requirements in Table 503.2.

An activity of DOE or other interested parties could be to develop a standard to test and calculate appropriate equivalent performance factors for this heating and cooling equipment.

**4.6.3 Improved Control Strategies, including Smart or Adaptive Controls**

The availability of inexpensive microprocessors and sensors enables the development of any number of innovative control strategies. An example is an optimal-start adaptive controller for a high-mass building. The controller would determine the proper time to begin heating or cooling the building to achieve the normal setpoint after a return from night setback. Outdoor, indoor, and thermal-mass temperatures could be used for the required calculations. The controller could be designed to adapt to the building and HVAC system and tailor the calculations to their particular characteristics. Many other control strategies could be developed or conceived.

A second control strategy is resetting of the supply air temperature. This is widely done in commercial building HVAC systems. Increasing the supply air temperature in response to less-than-design cooling loads leads to an increase in the coefficient of performance (COP) for the cooling unit. This saves cooling energy. A smart-enough controller and appropriate sensors could be used to minimize energy use of the cooling unit and a variable speed supply fan by varying both the supply air temperature and flow rate, while meeting the required instantaneous loads.

There do not appear to be any restrictions in the codes for such control strategies. The only requirements for HVAC control in the IECC include the need for a setback thermostat<sup>412</sup> and control requirements for a humidistat if one is installed.<sup>413</sup>

**4.6.4 Variable-speed Fans or Pumps**

Variable-speed motors for fans and pumps provide improved part-load efficiency compared to cycled single-speed motors. Variable-speed supply air fans also provide more uniform temperatures than single-speed units.

There do not appear to be any restrictions in the codes on the use of variable-speed fan or pump motors. A subtlety could be involved with the required “Transport Factor” defined as the ratio of the delivered cooling and the fan input power.<sup>414</sup> It is possible that this ratio could exceed the required value of 5.5 for some part-load ratios, even if the full-load

conditions meet the requirement. This issue is likely beyond the interest of most code officials.

#### **4.6.5 High-efficiency Motors**

Motors are available in a range of efficiencies, with the efficiency increasing with cost. Supply fan and hydronic system pump motors are not included in the minimum energy performance requirements for central heating and cooling equipment in the codes. The only direct code requirement is the transport factor defined above.

There are certainly no restrictions on increasing the efficiency of fan or pump motors in the codes, as long as the transport factor requirement is achieved.

#### **4.6.6 Mechanical Ventilation**

Mechanical ventilation systems are used to provide the minimum outside air requirements in tight buildings, or HVAC systems can be designed to advantageously introduce outside air into the supply air stream. The former is often done with a dedicated mechanical ventilation system. The latter is typical of commercial building air handlers. In either case, “The mechanical ventilation must produce 0.35 ACH for the ventilated space or 15 CFM of outside air for each occupant, based on 2 occupants in the first bedroom and 1 in each other bedroom.”<sup>415</sup>

The simplest mechanical ventilation system considered here is a dedicated system of ducts and fans that brings the required amount of air into the building, distributes it to the zones, and exhausts a similar quantity of building air to the outside. This system typically operates continuously. There are no code restrictions on its use other than those concerning the duct construction, fan electric connections, and so forth. The problem with this type of system is that it introduces very cold or very hot and humid air when it increases the heating or cooling loads. Three strategies can be followed to reduce such loads.

Air-to-air heat exchangers can be placed to transfer sensible or sensible and latent energy from the exhaust air stream to the intake air stream. During heating periods this will pre-heat the incoming air, and reduce the associated heating loads the HVAC system must meet. In cooling periods, the incoming air is cooled and, if latent heat is transferred, may be reduced in humidity. This decreases the associated cooling loads. There are no code restrictions on this type of equipment other than it must be listed as appropriately tested.

Economizers vary the amount of outside ventilation air depending on the ambient conditions. They always admit at least the minimum flow of air required by the code. However, if the HVAC system is in cooling mode, and the outdoor air is cooler than the return air flow, the economizer opens up to allow as much as 100% of the supply air to be outside air. This is the equivalent of opening up the window when it is cool outside. The increased outside air flow reduces the amount of cooling energy needed from the HVAC equipment. Economizers are common on commercial HVAC systems, but are not typical for residential scale systems. There are also no code restrictions on this type of equipment other than it must be listed as appropriately tested.

Ventilation air is required in buildings to supply oxygen to the occupants and to remove indoor pollutants.<sup>416</sup> Minimum ventilation-air requirements are designed to meet both these needs. Again, the airflow rates are based on a minimum of “0.35 ACH or 15 cfm per person, whichever is greater.”<sup>417</sup> However, an exception is allowed if a “registered design professional demonstrates that an engineered ventilation system design will prevent the maximum concentration of contaminants from exceeding that obtainable by the rate of outdoor air ventilation determined in accordance with Section 403.3 . . . .”<sup>418</sup> Commercial buildings use CO<sub>2</sub> sensors to implement exactly this type of control. It is reasonable to expect similar systems to be available for residential applications. Again, there are no additional code restrictions on this type of equipment other than it must be listed as appropriately tested.

#### **4.6.7 Evaporative Cooling**

When water is evaporated, the air temperature is reduced. In sufficiently dry climates, evaporative cooling systems use this principle to produce cooling with much less electric energy than conventional air conditioners and chillers. The IMC has regulations on the location,<sup>419</sup> water supply protection,<sup>420</sup> and other features of systems that may be applied to evaporative cooling equipment. No additional code restrictions apply to this type of equipment other than it must be listed as appropriately tested.

#### **4.6.8 Multiple Zoning in Buildings**

Multiple zoning allows energy efficiency by enabling relaxed thermostat setpoints and schedules in the different zones. Bedrooms can be maintained cooler during days in the heating season while other rooms may be maintained at higher setpoints. Multiple zoning is often used in hydronic residential heating systems. Commercial forced-air systems are commonly zoned by solar exposure or occupancy. Similar technology could be applied to residential forced air systems. There are no code restrictions that limit this strategy in residential buildings.

#### **4.6.9 Ground-source Heat Pumps**

Ground-source heat pumps use the relative constant and temperate ground and/or groundwater temperature as the heat source during heating mode. Because this temperature is higher than the outdoors, the coefficient of performance of the heat pump is increased. A variety of schemes are used to develop adequate thermal contact with the ground heat source. A closed loop of pipe can be laid in the ground with sufficient length to provide the necessary heat-transfer area. Alternately, water can be pumped from the ground for use as the heat source. This water can be sent to a drain or injected back into the ground. In either case, other than the requirements for other types of plumbing systems, there is no language in any of the codes that regulates the underground piping and related equipment. It may be in the best interest of constituents of this technology to develop appropriate code language for the piping, the various earth-contact strategies, and related equipment. The above-ground portions of heat pumps are covered in the IRC

as to the required duct sizes<sup>421</sup> and foundations and supports.<sup>422</sup> Of course, like other HVAC equipment, heat-pump equipment must be listed.

#### ***4.6.10 Gas cooling, including Engine-driven Heat Pumps and Absorption Cooling***

If the relative price structures warrant it, natural gas cooling equipment may be less expensive than typical electric driven compression cooling. These installations must meet the code requirements for gas piping, connections, cut-off devices, and other equipment.<sup>423</sup> Natural gas-powered engines must also meet the requirements of NFPA 37.<sup>424</sup> The IRC has requirements for absorption cooling equipment, including the removal of condensate, piping insulation, and pressure relief protection.<sup>425</sup> No additional code restrictions apply to either type of equipment other than it must be listed as appropriately tested.

#### ***4.6.11 Innovative Heating, Ventilation, and Air Conditioning (HVAC) Systems and Systems Analysis of the IECC***

##### **Improved Efficiency**

There are no obstacles to allowing full energy credit for HVAC equipment with higher efficiency levels. The equipment should be modeled with proper design load and part-load efficiency data, and default values for these parameters in the analysis program should be avoided.

##### **Equipment with Part-Load Curves Tailored to Real-World Load Histograms**

There are no obstacles to allowing full energy credit for HVAC equipment with improved part-load efficiency levels. The equipment should be modeled with proper design load and part-load efficiency data, and default values for these parameters in the analysis program should be avoided.

##### **Improved Control Strategies, including Smart or Adaptive Controls**

There are restrictions in the performance path criteria that will limit the allowed energy credits for some of these strategies. The allowable parameters for zone thermostat setpoints are presented in IECC Table 402.1.3.5. This may, for example, not allow the adaptive optimal return from night setback described above. There is no discussion of HVAC system level control strategies like the supply air reset previously described. Presumably, because there is no language constraining such strategies, it would be allowed in the analysis of the proposed design. It is difficult to find a rationale for restricting the potential control strategies. They represent major energy savings potentials at relatively small costs. As such, the following should be added to the performance path language.

**402.1.3.5.1 Advanced control strategies in the Proposed design.** HVAC system-related control parameters, setpoints, and algorithms shall be modeled as realistically as possible by the analysis tool.

## Variable-speed Fans or Pumps

Variable-speed motors for fans and pumps are not discussed in the performance path language. Presumably the energy credits for this technology are allowed if such equipment is properly modeled in the analysis of the proposed design. Some analysis tools may not be capable of modeling variable-speed pumps and fans.

## High-efficiency Motors

High efficiency motors for fans and pumps are not discussed in the performance path language. Presumably the energy credits for this technology are allowed if such equipment is properly modeled in the analysis of the proposed design.

## Mechanical Ventilation

Mechanical ventilation is not explicitly discussed in the performance path. However, air infiltration is discussed and is germane to the analysis of mechanical ventilation systems.<sup>426</sup> The air-infiltration rate for the standard design is the product of the normalized leakage and a weather factor. The normalized leakage is set at 0.57 for the standard design. The weather factor is “given by ASHRAE 136,<sup>427</sup> as taken from the weather station nearest the building site.”<sup>428</sup> Any lower infiltration rates for the proposed design must be certified by a blower door test, and no energy credits are allowed for air change values below 0.35 ACH.<sup>429</sup> These requirements restrict the energy credits allowed for some types of mechanical ventilation schemes. Language can be added as exceptions to this paragraph to allow such credit.

**Exception 1. Mechanical ventilation.** If mechanical ventilation systems are present, air-flow rate measurements of the supplied ventilation air can be used to calculate the air change rate used in the proposed design.

**Exception 2. Heat recovery.** If heat recovery is installed between the ventilation air and exhaust air ducts, the allowable energy credit shall be based on the measured air-flow rates and the effectiveness of the heat exchanger. Sensible energy transfer is allowed for heating, and both sensible and latent energy transfer is allowed for cooling.

**Exception 3. CO<sub>2</sub> sensors.** If CO<sub>2</sub> sensors are installed, they shall be calibrated to allow 0.35 ACH of ventilation air flow when the building is fully occupied with two people for the first bedroom and one person for other bedrooms. The ventilation air-flow rate shall then be allowed to fall below this rate during periods of reduced occupancy. In the analysis of the proposed design, reasonable schedules for occupancy and the ventilation air flows shall be used to provide proper credit for this technology. (Note that a source for the “reasonable schedules for occupancy” needs to be determined.)

## Evaporative Cooling

Evaporative cooling is not discussed in the performance path language. Presumably the energy credits for this technology are allowed if such equipment is properly modeled in the analysis of the proposed design. The performance path states that the standard and proposed designs “shall utilize the same energy source(s) for the same functions.”<sup>430</sup> This should not restrict the energy credits for evaporative cooling because electricity is used both for running the compressors in air conditioners and running the fan and pumps in evaporative-cooling equipment.

## Multiple Zoning in Buildings

The number of zones in the standard and proposed designs is limited to two per living unit in the performance path.<sup>431</sup> This raises the issue, which is not discussed in the performance path language, of how to define the HVAC system for the standard design. It seems reasonable that the HVAC system for the standard design should be based on the common practice in the location where the proposed design is to be built. Typically, most locations presently use compression-cooling, forced-air conditioners with a single building zone. Regardless, the restriction on the number of zones in the analysis of the proposed design is not reasonable. The code language should be changed to allow the actual number of unique HVAC zones to be modeled:

**Exception. Multiple-zone HVAC systems.** If HVAC systems with multiple-zone capabilities are installed, then the actual number of zones and their unique thermostat and other schedules shall be used in the analysis of the proposed design.

## Ground-source Heat Pumps

Ground-source heat pumps are not discussed in the performance path language. Presumably the energy credits for this technology are allowed if such equipment is properly modeled in the analysis of the proposed design. There is no discussion of the appropriate ground temperatures to use for this type of analysis. Presumably, the monthly average ground temperatures from the TMY weather data would be used.

## Gas Cooling, including Engine-driven Heat Pumps and Absorption Cooling

The performance path states that the standard and proposed designs “shall utilize the same energy source(s) for the same functions.”<sup>432</sup> This requirement disallows any potential energy savings with fuel-switching technologies that may not be important because the energy analysis is based on the site energy, not the source energy or the cost of energy.<sup>433</sup> This requirement to use the same energy source(s) for the same functions will always bias against the substitution of natural gas for electricity. There is no change in the performance-path language that will mitigate this problem unless the overall analysis is based on energy costs or source energy consumption as opposed to the present site energy-consumption criteria.

---

<sup>394</sup> IRC 1302.1 Appliances.

- 
- <sup>395</sup> IRC 1401.2 Access.
- <sup>396</sup> IRC 1401.5 Attic installations.
- <sup>397</sup> IRC 1401.6 Crawl space installations.
- <sup>398</sup> IRC 1401.7 Exterior installations.
- <sup>399</sup> IRC 1402.2 Clearances, for example.
- <sup>400</sup> Air Conditioning Contractors of America Manual J. Load Calculations for Residential Winter and Summer Air Conditioning.
- <sup>401</sup> IRC 1401.4 Sizing.
- <sup>402</sup> IMC 202 General definitions.
- <sup>403</sup> IMC 702.1 Air from the same room or space.
- <sup>404</sup> IMC 703.1 Outdoor Air (Condition 1).
- <sup>405</sup> IMC 703.1 Outdoor Air (Condition 2).
- <sup>406</sup> IMC 707 Forced Combustion Supply Air.
- <sup>407</sup> IRC 2001.1 Buildings of unusually tight construction.
- <sup>408</sup> IECC Table 503.2 Minimum Equipment Performance, for example.
- <sup>409</sup> David Wortman, personal experience.
- <sup>410</sup> IECC 201 General definitions.
- <sup>411</sup> IECC 503.2 Mechanical equipment efficiency.
- <sup>412</sup> IECC 503.3.2.2 Thermostatic control capabilities.
- <sup>413</sup> IECC 503.3.2.4 Humidistat.
- <sup>414</sup> IECC 503.3.3.6 Transport energy.
- <sup>415</sup> Ibid.
- <sup>416</sup> IMC 403.2 Outdoor air required.
- <sup>417</sup> IMC Table 403.3 Required Outdoor Ventilation Air.
- <sup>418</sup> IMC 403.2 Outdoor air required. Exception.
- <sup>419</sup> IMC 911.3 Location.
- <sup>420</sup> IMC 011.5 Water supply.
- <sup>421</sup> IRC 1403.1 Heat pumps.
- <sup>422</sup> IRC Foundations and supports.
- <sup>423</sup> IFGC Chapter 4 Gas Piping Installations.
- <sup>424</sup> National Fire Protection Association 37. Stationary Combustion Engines and Gas Turbines.
- <sup>425</sup> IRC 2402 Absorption Cooling Equipment.
- <sup>426</sup> IECC 402.1.3.10 Air infiltration.
- <sup>427</sup> American Society of Heating Refrigeration and Air Conditioning Engineers Standard 136. Method of Determining Air Change Rates in Detached Dwellings.
- <sup>428</sup> IECC 402.1.3.10 Air infiltration.
- <sup>429</sup> Ibid.

---

<sup>430</sup> IECC 402.1.2 Proposed design.

<sup>431</sup> IECC 402.1.3.5 Heating and cooling controls.

<sup>432</sup> IECC 402.1.2 Proposed design.

<sup>433</sup> IECC 402.2.3 Site energy.

## **4.7 Electrical Lighting, Daylighting, and Associated Controls**

The technologies considered here include high efficiency lamps and fixtures, local and core daylighting systems, as well as light pipe technologies.

Efficient lamps and fixtures are not addressed in the codes.

The only reference to daylighting in any of the codes is the definition for Solar Energy Source in the IECC: “Source of natural daylighting and of thermal, chemical or electrical energy derived directly from conversion of incident solar radiation.”<sup>434</sup> Innovative lighting technologies are not discussed.

Daylighting is the use of solar radiation to displace interior electric lighting. Sensor/controller units are available which detect the light available from solar radiation. These units maintain minimum, pre-set interior lighting levels by dimming or turning off electric lights. Daylighting controls are more typically installed in commercial buildings where the electric lights are usually “on” during the daytime hours. Their application in residential buildings is limited, but possible, and will be considered here.

Daylighting strategies also include windows and other means for admitting light into the building. Innovative window strategies include glazing materials that admit a relatively high amount of visible light while blocking much of the heat producing infrared. Code implications of innovative fenestration products have been previously discussed in this report. The placement of windows for daylighting ranges from using existing windows, to the addition of clerestories, light shelves or skylights, or to various core daylighting strategies. The latter can involve multi-story light shafts that distribute light from roof mounted glazed openings to the core areas of lower floors. Only the first two strategies are typically used in residential buildings. Skylight shafts must be insulated to “no less than R-13 in climates of 0-4000 heating-degree-days and R-19” otherwise.<sup>435</sup> “The skylight shaft thermal performance shall not be included in the roof thermal transmission coefficient calculation.”<sup>436</sup>

Light pipe technology is the use of fiber optic cables or guides to distribute the light produced from a central source. The light source is often placed outside the conditioned space, reducing the building internal gains and associated cooling loads. This technology is not widely used, and is again more applicable in internal gain dominated commercial buildings.

Finally, improvements in the efficiency of electric light sources will be considered in regards to their impact on compliance with the IECC prescriptive and performance paths.

### **4.7.1 Code Implications of High-efficiency Lamps and Fixtures**

There is very little reference to lighting in the various codes. Minimum lighting levels are specified for commercial and high-rise residential buildings, but detached one and two-family buildings and the dwelling portions of larger buildings are specifically

exempted.<sup>437</sup> There are many requirements for the installation of lighting in the NEC, but nothing that constrains the installed lighting power density.

#### **4.7.2 Code Implications of Daylighting Controls and Associated Circuits**

The simplest daylighting control strategy is a sensor integrated into a light switch that turns lights on or off. These have no Code implications except that the sensor/switch must be UL or comparably listed.

A similar system has the sensor remotely located from the switch. This is done to place the sensor near where the light is actually perceived. There are additional code requirements for the sensor wire. These circuits must comply with the requirements of the NEC Article 725 part C. Class 2 and Class 3 Circuits. The cable used for instrumentation signals in dwellings must be rated Type CL2X or CL3X or better.<sup>438</sup> Cables in ducts delivering environmental air must be rated CL2P or CL3P or better.<sup>439</sup> Other permitted cable types are listed in Table 725-71 of the NEC. Instrumentation wire, Type ITC, is apparently not approved for use in dwellings<sup>440</sup> because of concerns about the fire resistance of the cabling. There are many requirements for the wiring methods used for the signal wiring. The signal carrying cables cannot be in close contact with power carrying wires unless one of a number of specific isolation methods are used. These are described in NEC Article 725-54.

A third approach involves fluorescent lamps and electronic ballasts. The light sensor sends a voltage signal to the ballast that changes the lamp output to maintain constant lighting levels. The ballasts need to be UL or comparably listed and the control wiring needs to conform to the requirements described in the previous paragraph.

#### **4.7.3 Code Implications of Windows Associated with Daylighting**

Daylighting controls can operate in buildings with no changes to the existing or normal placement or types of windows. Obviously this has no Code implications for the windows. However, there are two design issues with daylighting windows that can affect how they are chosen and where they are installed. First, the type of glazing materials can be chosen to try to optimize the mix of admitted heat and visible light. Code requirements for innovative windows have been previously covered in this report.

The location of the windows, skylights, and clerestories can be selected to optimize the distribution of daylight in the building. In a typical residential building, this free light is usually concentrated around the outside perimeter. The glazing in daylit buildings can be designed to distribute the free light throughout the entire building. In the IECC prescriptive path, the size and location of windows is only considered as its impact on the overall U-value for each wall/window assembly.<sup>441</sup> Increasing the window area for daylighting and attempting prescriptive path compliance will likely require decreasing the U-value in the associated opaque wall assemblies. “Walls” that are essentially all windows, like a clerestory, will not meet the maximum wall/window U-value requirements of the IECC prescriptive path. These can meet compliance because the IECC allows an individual component to “deviate from the U-values specified . . .

provided the total thermal transmission heat gain or loss for the proposed building envelope does not exceed the total heat gain or loss resulting from the proposed building's conformance to the values specified. . . ."<sup>442</sup> In other words, if necessary, the U-values of the other walls or other surfaces can be decreased to account for the clerestory not meeting component compliance.

#### **4.7.4 Code Implications of Core Daylighting and Light Pipes**

Both of these technologies include the distribution of light from a remote source. In core daylighting, the source is a skylight, roof window, or similar aperture. For light pipes, the source can be the same as for daylighting or it can be a remote electric light source. The path the light takes to the lit spaces can potentially be vertical shafts through the roof, attic, and ceiling; tubes with reflective inner surfaces; fiber optic cables; or yet-to-be-developed technologies. Any roof penetrations need to be made weather tight. "Flashings shall be installed . . . around roof openings."<sup>443</sup> Plastic glazing components of these systems would also need to meet the requirements for sloped glazing. For an "installation of glass or other transparent or translucent glazing material installed at a slope of 15 degrees or more from vertical,"<sup>444</sup> only certain types of glazing materials may be used. These include "Fully tempered glass, Heat-strengthened glass, Wired glass and Approved rigid plastics."<sup>445</sup> There is no list of "Approved rigid plastics." However, in the IRC, approved "refers to approval by the code official as the result of investigation and tests conducted by him, or by reason of accepted principles or tests by nationally recognized organizations."<sup>446</sup> Rigid plastic materials in such plastic glazing applications would need to meet the testing standards for exterior glazing, such as CPSC 16 CFR 1202<sup>447</sup> or a similar standard. Additionally, "Laminated glass with a minimum 0.015 inch polyvinyl butyral interlayer for glass panes 16 ft<sup>2</sup> or less in area: for larger sizes, the minimum interlayer thickness shall be 0.030 inch."<sup>448</sup> Any penetrations between floors in a roof or ceiling need to be framed to Code to maintain structural integrity.<sup>449</sup> There does not appear to be language in the code concerning the fire spread potential of light shafts and other similar features. However, local code inspectors may raise issues with such design features.

#### **4.7.5 Innovative Electrical Lighting and Daylighting and Systems Analysis of the IECC**

There is no credit given to improved lighting design, lamps, or fixtures in the IECC. Limitations on the lighting power density are specifically excluded from the prescriptive path. Values for internal heat gain levels are specified in the performance path.<sup>450</sup> These internal gain levels would be reduced if more efficient lighting is used in the proposed building. Reduced internal gains generally reduce cooling loads and increase heating loads. Language that could be added to the IECC to improve this is:

**402.1.3.6.1 Real internal gain levels for the proposed building.** Internal gain levels and schedules based on the actual installed lighting power densities, appliances and number of occupants can be used to comply with the requirements of this chapter. Lighting, appliance, equipment, and occupant schedules can be taken from an appropriate source. Occupant related heat gains must be taken

from the ASHRAE Handbook of Fundamentals. (Note that an appropriate source is not specified.)

Daylighting systems decrease building energy use by reducing electricity used for lighting, which also reduces coincident cooling loads. Daylighting systems also increase the heating loads. The IRC does not allow credit for the energy impacts of daylighting systems.

There is no mention of RE sources, including sunlight used for daylighting applications, in the IECC prescriptive compliance path.<sup>451</sup> The IECC performance path allows credit for the use.

However, the steps necessary to calculate and document this energy credit are generally expensive and complex. It is in the interest of manufacturers and other interest groups to make compliance with the IECC an easier process.

The IECC performance path contains provisions to account for energy from RE sources. “Renewable energy shall be permitted to be excluded from the total energy consumption allowed for the building. . . .”<sup>452</sup> For solar energy, the glazing must be “shaded from direct rays of the sun during periods when mechanical cooling is required.”<sup>453</sup> This prescriptive requirement in the performance path is illogical and may present a barrier to the design and implementation of daylighting systems. A separate definition should be developed for daylighting systems, such as:

**403.1.5 Daylighting systems energy exclusion.** Lighting energy savings from daylighting systems are permitted. Daylighting apertures are excluded from the requirements of Sections 403.1.1.2 and 403.1.2.2. Energy savings from daylighting systems shall be calculated according to the methods in Section 402, except that any requirements for exterior shading or the orientation of the glazing in Sections 402.1.3.1 and 403.1.3.2 are not applicable. The analysis must use reasonable hourly internal gain schedules for the standard design electric lighting loads.<sup>454</sup> (Note that an appropriate source for the internal gain schedules is not specified.)

Many of the hourly simulation tools that would be applicable for the performance path analysis may not be capable of the daylighting analysis. Among other requirements, the analysis tool must be capable of tracking and reporting electrical energy use as well as heating- and cooling-related energy use. Because daylighting is very specific to building design and location, the development of an accurate simplified approach may be difficult or impossible. The U.S. Department of Energy could look into this possibility and develop appropriate tables or maps to be used for prescriptive path compliance.

A report must be prepared detailing the proposed design and analysis.<sup>455</sup> If RE is used, it needs to be separately identified from the overall building energy use. Supporting documentation should also be submitted.

- 
- <sup>434</sup> IECC 201 General Definitions.
- <sup>435</sup> IECC 502.2.1.2 Roof/ceiling.
- <sup>436</sup> Ibid.
- <sup>437</sup> IECC 505.2 Lighting power budget.
- <sup>438</sup> NEC 725-71(c) Types CL2X and CL3X.
- <sup>439</sup> NEC 725-61(a) Plenum.
- <sup>440</sup> NEC 727-2 Uses permitted.
- <sup>441</sup> IECC 502.2.1.1 Walls, for example. There are similar requirements throughout Chapter 5 of the IECC.
- <sup>442</sup> IECC 502.2.2 Compliance by total building envelope performance.
- <sup>443</sup> IRC 903.2.1 Locations.
- <sup>444</sup> IRC 308.6.1 Definition of skylights and sloped glazing.
- <sup>445</sup> IRC 308.6.2 Permitted materials for skylights and sloped glazing.
- <sup>446</sup> IRC 202 General Building Definitions.
- <sup>447</sup> Consumer Product Safety Commission 16 CFR 1201 Safety Standard for Architectural Glazing.
- <sup>448</sup> IRC 308.6.2 Permitted materials for skylights and sloped glazing.
- <sup>449</sup> IRC 804.3.9 Framing of openings.
- <sup>450</sup> IECC 402.1.3.6 Internal heat gains (constants).
- <sup>451</sup> IECC Chapter 5 Residential Building Design by Component Performance Approach.
- <sup>452</sup> IECC 403.1 Renewable Energy Source Analysis – General.
- <sup>453</sup> IECC 403.1.1.2 Shading, or IECC 403.1.2.2 Shading.
- <sup>454</sup> Ibid.
- <sup>455</sup> IECC 403.2 Documentation.

## **4.8 Innovative Thermal Storage Systems**

These systems store heating or cooling energy to be more economically applied to appropriate loads at other times of the day or week. “Heat” or “cool” is typically stored as sensible energy in liquids or solids or as latent energy in a liquid/solid mixture or other phase-change material. Heating energy is usually provided by electricity or fossil fuel. Cooling energy is usually provided by a chiller. Energy is distributed from the storage by hot or chilled water or air.

### **4.8.1 General Code Considerations**

Thermal storage equipment is not directly addressed by any of the reviewed codes. However, these systems are typically made up of components that are covered by Code requirements. These components include electric or fuel furnaces, thermal storage tanks, pumps and associated electrical wiring, plumbing, and ductwork. Water and water/ice cooling storage systems need a chiller with a liquid cooled evaporator. This type of equipment is not commonly applied to residential applications and is typically used in commercial buildings.

It would be useful to add a section or chapter to the IRC or IMC to include requirements for thermal storage systems. The chapter could have the following sections, each containing relevant requirements or references to other sections of Code or appropriate standards:

- Thermal storage tanks for liquids
- Thermal storage tanks for solids
- Electric heating equipment for thermal storage
- Fuel-fired heating equipment for thermal storage
- Refrigeration equipment for thermal storage
- Pumps for thermal storage
- Piping for thermal storage
- Ductwork for thermal storage
- Electrical requirements for thermal storage systems.

There are some code requirements that work against compliance of thermal storage equipment.

### **Assumed Annual Performance Requirements for HVAC Equipment**

The minimum performance for HVAC cooling and heating equipment is specified in the codes as integrated typical performance factors. These include the Annual Fuel Utilization Efficiency (AFUE) for furnaces, Heating Seasonal Performance Factor (HSPF) for heat pump heating and the Seasonal Energy Efficiency Ratio (SEER) for air conditioners and chillers.<sup>456,457</sup> These performance factors are calculated with assumptions on the fraction of each year the equipment operates at a series of part-load values. Heating or cooling equipment in well-designed thermal storage systems will

operate at high part-load levels when they are operating. For example, they will not cycle on and off like a lightly loaded air conditioner. Residential heating and cooling equipment is typically less efficient at lower part-load fractions. Therefore, heating or cooling equipment will operate at a higher annual average efficiency as part of a thermal storage system than as a stand-alone unit conditioning a building. The present compliance requirements may be penalizing thermal storage systems by requiring higher levels for the above performance factors than is required to provide equal annual efficiency and energy use. An addition to the IECC minimum equipment efficiency requirements could read:

**503.2.1 Exception for equipment as part of thermal storage systems.** Heating and cooling equipment that are parts of thermal storage systems shall comply with this code if testing to appropriate standards (or recognized engineering analysis) shows annual performance equal to or higher than the appropriate requirements in Table 503.2.

An activity of DOE or other interested parties could be to develop a standard to test and calculate appropriate equivalent performance factors for this heating and cooling equipment.

### System Sizing for Thermal Storage Systems

The heating or cooling capacity for thermal storage systems is typically larger than the capacity of the furnace/boiler or chiller. These systems can be designed to provide heating/cooling from both the storage system and heater/cooler during extreme conditions. This total capacity may not be recognized as meeting the sizing requirements of the IRC.<sup>458</sup> A standard needs to be developed to determine the appropriate energy rate capacity for different thermal storage system designs. Additional language could be added to include these considerations:

**1401.4.1 Sizing of heating and cooling equipment for thermal storage systems.** The capacity for heating and cooling equipment that is part of thermal storage systems shall allow a credit for the heating and cooling capacities from the storage subsystems.

### **4.8.2 Innovative Thermal Storage Systems and Systems Analysis of the IECC**

The reason for using thermal storage systems is not to reduce energy use, but rather to reduce energy costs, typically because of reduced electric demand during on-peak hours. A possible additional benefit is a reduction in first costs associated with smaller capacity cooling or heating equipment.

These considerations are not given credit in the IECC. Indeed, thermal storage systems usually increase the overall energy use. Cooling does not just need to be created, it also needs to be stored. There are always standby losses when thermal energy is stored at other than ambient temperature conditions. Increased energy use as a result of the use of

thermal storage systems works directly against compliance with the IECC requirements.<sup>459</sup>

This is a case where the codes limit potentially good design approaches by building and mechanical system designers. Language should be added to the IECC to prevent this penalty if the use of thermal storage systems is economically warranted. Because there is not other economically based requirements in any of the codes, formulation of this added language will likely require much discussion between interested parties and will not be attempted here. However, to fairly evaluate thermal storage designs, the performance path should allow compliance through either an energy-based or energy-cost-based comparison between the standard and proposed designs.

#### **4.9 Buildings Requiring No Heating and/or Cooling Equipment**

Specially designed buildings can maintain adequate comfort conditions without relying on heating and/or cooling equipment in many locations.

The IRC states that “When required by Table 301.2a, every dwelling unit shall be provided with heating facilities capable of maintaining a room temperature of 68°F at a point 3 feet above the floor at the design temperature in all habitable rooms.”<sup>460</sup> The information in IRC Table 301.2a is entered for each locality, and includes the appropriate “Winter Design Temp. For Htg. Facilities.” Note 5 to this table states “If heating facilities are not required in this climate, enter ‘None Required.’” Presumably this is applicable to areas without cold or cool seasons, like Hawaii or southern Florida.

There is no language in any of the reviewed codes that allows a variance from these requirements.

There are also no requirements in any of the reviewed codes that require cooling equipment in buildings.

Convincing local code officials that a building will maintain adequate heating setpoints will be difficult unless there are additions made to the IRC or other applicable Code. The first logical step in providing the information needed to show the ability to maintain the heating setpoint is a detailed hourly analysis based simulation of the building. This is similar to the requirements already found in the IECC performance path with the added capability of showing hourly temperatures on cold days for each building zone. The need to show that the heating setpoint is maintained “at a point 3 ft above the floor” may be troublesome. Most building simulations model the thermal zones as having mixed air, in that zone air is modeled as a single, average temperature. Of course, real buildings have temperature variations in different areas of the same room or thermal zone. In real buildings, however, the only temperature that is actually maintained by the heating system is that found at the thermostat(s). As such, the ability for buildings without heating systems to comply with the codes requires the following language added to the IRC:

**303.6.1 Exception. Heating not required.** Heating systems are not required if hourly thermal analysis, performed as described in Chapter 4 of the IECC, shows that the minimum required room temperature defined in 303.6 is maintained for every conditioned building zone for every hour of the analysis year with an ambient temperature at or above the winter design heating temperature in Table 301.2a of this Code. This requires that the analysis method perform a true hourly energy analysis, can model simultaneous multiple zones, and can produce outputs for the hourly zone and ambient temperatures. The modeling of a single, mixed air temperature for each zone is sufficient to meet these requirements. The weather data used to drive the simulation must have statistically correct values for and numbers of extreme ambient temperatures.

A special situation can occur for high thermal mass passive-solar buildings. In these buildings the radiant heat from the wall surfaces may maintain comfortable zone conditions even if the dry bulb air temperature drops below 68°F. Local code officials are not likely to accept this subtlety. Guidelines in this area could be an area for research by DOE.

The interior temperatures of building with no heating or cooling equipment are sensitive to the choice of design weather data. A potential DOE activity is to determine the appropriateness of TMY or other weather data sources for this analysis.

#### **4.9.1 *Buildings Requiring No Heating and/or Cooling Equipment and Systems Analysis of the IECC***

There could be energy savings between the proposed design with no heating system and the standard design if it is otherwise identical to the standard design. The requirements are that the building be maintained at 68°F at the specified ambient design temperature. If that design temperature is above the lowest actual ambient temperature, energy will be saved when these lower ambient temperatures are reached. There is presently no language in the IECC to allow credit for these subtle energy savings. However, it is almost certain that any building that can be shown to not need a heating system will pass the other energy requirements of the IECC without the need for this additional energy credit.

Passive-solar buildings that maintain comfort without necessarily maintaining the 68°F temperatures required by the codes need to be analyzed with analysis tools that can model the interior radiant environment. Not all of the tools that would otherwise be appropriate for the performance path analysis can do this. DOE could publish a guideline as to which tools are acceptable, and how they should be used to correctly model these effects and report the appropriate output variables.

---

<sup>456</sup> IECC 201 General definitions.

<sup>457</sup> IECC 503.2 Mechanical equipment efficiency.

---

<sup>458</sup> IRC 1401.4 Sizing.

<sup>459</sup> It should be noted that thermal storage may not always result in increased energy usage. In a cool storage system, if there are sufficiently large diurnal temperature variations, the increased nighttime chiller COP relative to the daytime might produce overall system energy savings. This is not likely or typical.

<sup>460</sup> IRC 303.6. Required heating.

#### 4.10 Buildings Requiring No Conventional Air Distribution (Duct) Systems

There are no requirements in any of the reviewed codes that require ductwork for air heating appliances. There are extensive requirements for hydronic<sup>461</sup> and electrically heated<sup>462</sup> heating systems. While these technically do not have ducts, they will not be considered here. There are no requirements for buildings without heating and cooling systems to have ducts, which could include some passive solar designs.

The IRC states that “When required by Table 301.2a, every dwelling unit shall be provided with heating facilities capable of maintaining a room temperature of 68°F at a point 3 ft above the floor at the design temperature in all habitable rooms.”<sup>463</sup> This language implies that any type of heating distribution system must be capable of providing adequate heating under design conditions to every conditioned space. Because every building design is different, it is difficult to imagine that a standard could be developed to guarantee that a heating system without ducts could provide adequate heating for any building design and climate. As such, this is one area where the local code officials will likely need to be convinced individually that such heating system designs are adequate to pass the code requirements. This is allowed under IRC sections 104.11<sup>464</sup> and 104.11.1.<sup>465</sup> These sections allow alternative designs to be used and the code official can require tests to show reasonable performance. Unfortunately, it may be quite difficult to run such tests in a timely manner, because outdoor heating design temperatures are available only a small fraction of the time. Because of this and the probable conservative nature of many code officials, it is unlikely that heating systems without some conventional form of distribution system will be widely accepted.

Ducts may also be required to supply ventilation air to the building zones. They are not required for naturally ventilated buildings. However, if a mechanical ventilation system is used, they need to be designed to “deliver the required rate of supply air to the occupied zone”<sup>466</sup> This implies that even if the heating system does not require ductwork, tight buildings could require ductwork only for the distribution of ventilation air.

---

<sup>461</sup> IMC Chapter 12 Hydronic Piping.

<sup>462</sup> NEC Article 424 Fixed Electric Space-Heating Equipment.

<sup>463</sup> IRC 303.6. Required heating.

<sup>464</sup> IRC 104.11 Alternative materials, design and methods of construction and equipment.

<sup>465</sup> IRC 104.11.1 Tests.

<sup>466</sup> IMC 403.1 Ventilation System.

## 4.11 Solar-Assisted Ventilation Systems

Transpired solar collectors are used to pre-heat building ventilation air. If the building is mechanically ventilated, the outside air is drawn across the transpired collector plate, which heats it, and is then delivered to the building.

In the IMC, equipment is defined as “All piping, ducts, vents . . . other than appliances which are permanently installed and integrated to provide control of environmental conditions for buildings.”<sup>467</sup> This technology is not directly addressed in the codes. Code officials will likely view these collectors as any or all of ductwork, solar collectors, and building walls.

### 4.11.1 Solar-Assisted Ventilation Systems as Ducts

The Code requirements for ductwork are in Chapter 6 of the IMC. There are a number of restrictions that may limit the use of existing wall structures as part of a transpired collector system. For example, stud wall cavities utilized as air plenums shall

1. “not be utilized as a plenum for supply air . . .
2. not be part of a required fire-resistance-rated assembly . . .
3. not convey air from more than one floor level . . .
4. comply with the floor penetration protection requirements of the building code . . .
5. be isolated from adjacent concealed spaces by approved fire-blocking . . . .”<sup>468</sup>

If transpired collectors are installed to use the stud wall cavities as air plena, these restrictions are applicable.

Ducts are required to be constructed of “iron, metal, aluminum or other approved material.”<sup>469</sup> Non-metallic ducts shall be constructed with “Class 0 or Class 1 material in accordance with UL 182.”<sup>470</sup> If the transpired collectors are considered ductwork, the glass covers may not meet these standards.

“Duct system penetrations of walls, floors, ceilings and roofs and air transfer openings in such building components shall be protected as required by the building code.”<sup>471</sup> The IRC has requirements for penetrations of fire-resistant rated wall assemblies, but these apply only to walls separating units in multi-dwelling buildings.<sup>472</sup> Fireblocking in all residential buildings is required “at openings around . . . ducts at ceiling and floor level, with an approved material to resist the free passage of flame and products of combustion.”<sup>473</sup> The wording of these requirements is not clear, and the developers of the IRC should be contacted for clarification. However, because the codes are always interpreted by local officials, it is reasonable to expect that any ducts that penetrate fire rated assemblies should, at a minimum, have fireblock materials to fill in all openings.

Because transpired collectors are exposed to ambient air and ambient temperatures, condensation may be a problem. The IMC requires that “provisions shall be made to prevent the formation of condensation on the exterior of any duct.”<sup>474</sup>

#### **4.11.2 Solar-Assisted Ventilation Systems as Solar Collectors**

The IMC defines an appliance as “a device or apparatus that is manufactured and designed to utilize energy and for which this code provides specific requirements.”<sup>475</sup> Because IMC Chapter 15 covers solar systems, transpired collectors will likely be considered as appliances. As such, they need to be listed and labeled<sup>476</sup> or otherwise approved by local code officials.<sup>477</sup> The unique characteristics and applications for these collectors indicate that a separate testing standard may need to be developed for them.

#### **4.11.3 Solar-Assisted Ventilation Systems as Building Walls**

Wall-mounted transpired collectors need to meet the thermal requirements of conventional wall construction, as discussed below. If the exterior of these collectors is glazed, the transpired solar collectors on the market now are not glazed. They will also need to meet the wind-loading requirements for vertical glazing.<sup>478</sup> For glazing within 15 degrees of vertical, a formula is given that relates the length, width, thickness, and type of glass and how the glass is supported to the design wind loading. Locating the collector glazing in a “hazardous location,”<sup>479</sup> such as within 36 inches horizontally of a walking surface, is not permitted without the use of special glazing materials.<sup>480</sup>

#### **4.11.4 Solar-Assisted Ventilation Systems and Systems Analysis of the IECC**

There is no method in either the IECC prescriptive path or performance path to allow appropriate credits for this technology. Transpired collectors are not discussed in the IECC.

These collectors can act as ducts, mechanical appliances, and wall components. Their impact on the thermal transmission of the walls they are installed on is beyond the scope of this report. The wall U-values will change depending whether or not air is flowing in the collectors and will also vary depending on the temperature of the flowing air.

The energy impact of transpired collectors could be determined under the analysis procedures in the performance path. However, this requires analysis software that can model both buildings and this technology. Appropriate software does not presently exist, except possibly in the research community. Development of software with this capability would aid in the design and implementation of the technology. It is possible that existing energy analysis programs could be modified with the additional capabilities to model this technology. However, the various aspects of this technology (as solar collectors, a wall layer, and part of the mechanical system) would make this a reasonably involved process. In particular, the changing effective wall U-value during operation of the transpired collectors is likely beyond the capabilities of DOE2 or other similar programs. This is an activity the DOE could pursue to aid in the more widespread application of this technology.

- 
- <sup>467</sup> IMC 202 General definitions.
- <sup>468</sup> IMC 602.3 Stud cavity and joist space plenums.
- <sup>469</sup> IMC 603.3 Metallic ducts.
- <sup>470</sup> IMC 603.4 Nonmetallic ducts.
- <sup>471</sup> IMC 603.6 Rigid duct penetrations.
- <sup>472</sup> IRC 320.4 Penetrations.
- <sup>473</sup> IRC 602.8 Fireblocking required.
- <sup>474</sup> IMC 603.11 Condensation.
- <sup>475</sup> IMC 202 General definitions.
- <sup>476</sup> IMC 301.3 Listed and labeled.
- <sup>477</sup> IMC 105 Approval.
- <sup>478</sup> IRC 308.5.1 Vertical glass.
- <sup>479</sup> IRC 308.4 Hazardous locations.
- <sup>480</sup> IRC 308.3 Human impact loads.

## 4.12 Desiccant Dehumidification Systems

These systems use materials with a natural affinity to adsorb water vapor to reduce the humidity in the ventilation or supply air. The moisture is removed from the desiccant, or regenerated, by heat from fuel, electric, or renewable sources.

There is no direct discussion of any humidity control systems in the codes. Recently adopted ASHRAE design weather data shows maximum cooling loads are under-predicted by traditional data, which focuses on dry-bulb temperature. When ventilation air makes up 15% of supply, moisture loads begin to dictate the capacity and Sensible Heat Ratio extremes an air-conditioning system must cover. The only reference to humidity control is “Humidistats used for comfort purposes shall be capable of being set to prevent the use of fossil fuel or electricity to reduce relative humidity below 60% or increase relative humidity above 30%.”<sup>481</sup> On the other hand, the codes allow the installation of such equipment, but it must be listed and labeled, unless otherwise approved. . . .<sup>482</sup> “Otherwise approved” means it is approved by the local code officials, which requires sufficient evidence of compliance or additional tests as authorized by the local officials.<sup>483</sup>

There is currently no system standard for desiccant-based, and such a system standard is potentially years off.<sup>484</sup> Moreover, these standards will almost certainly focus on commercial units.<sup>485</sup> If desiccant dehumidification systems are labeled and listed or otherwise approved, the code requirements for installation are the same as for similar HVAC equipment described in the previous section on Innovative Heating, Ventilation and Air Conditioning (HVAC) Systems.

### 4.12.1 Desiccant Dehumidification Systems and Systems Analysis of the IECC

Desiccant dehumidification systems save energy by reducing the latent cooling load on a downstream air conditioner or cooling coil and treating its portion of the load more efficiently. They also can provide improved indoor air quality and occupant comfort. Because conventional dehumidification uses a chiller with a coefficient of performance greater than one, it is possible that a desiccant system will use more site energy as defined in the IECC. However, the heating fuel used to regenerate desiccant systems is typically much less expensive, on an equivalent energy basis, than electricity. It, therefore, seems reasonable that to fairly evaluate desiccant systems, the performance path should allow compliance through either an energy-based or energy-cost-based comparison between the standard and proposed designs.

The IECC prescriptive path has no ability to allow a credit for these savings. The IECC performance path contains no language for any type of dehumidification. The addition of language to the IECC Chapter 4 can be used to account for the energy savings from this technology:

**402.1.3.5.1 Humidification controls.** If desiccant or other dehumidification equipment is included in the proposed design, the minimum and maximum humidity setpoints shall be 30 and 60 percent, respectively, for both the standard and proposed designs. The standard design mechanical system shall be capable of maintaining the maximum humidity setpoint.

---

<sup>481</sup> IECC 503.3.2.4 Humidistat.

<sup>482</sup> IMC 301.3 Listed and labeled.

<sup>483</sup> IMC 105 Approval.

<sup>484</sup> Steve Slayzak, correspondence

<sup>485</sup> Ibid.

## 5.0 Appendix A

### A Comparison of the SRCC Document OG-300 and the Reviewed Codes in Regards to Active Solar Hot Water Systems

The OG-300 document<sup>486</sup> (SRCC) describes a standard methodology for testing the performance parameters of active SHW systems, as well as issues related to the building code of these systems. Only the issues related to the building code are discussed here. SHW systems that pass the SRCC certification process will be considered labeled and listed for the purposes of the other codes reviewed in this document.

Certification under the SRCC does not overrule the requirements of the applicable building codes at the building location.<sup>487</sup> The SRCC also has many requirements for which there are no comparable requirements in the building codes. The remainder of this Appendix will list the building code related requirements in the SRCC and discuss the comparable requirements between these codes and OG-300. SRCC requirements that are not discussed are either not related to, or have no comparable requirements, in the building codes. Most of the OG-300 requirements are more stringent than may be required by local code officials working under the other reviewed codes in this report.

6.1.1.3 Thermal Expansion and 6.1.3.4 Expansion Tanks. The SRCC states that the system “shall include adequate provisions for the thermal contraction and expansion of heat transfer fluids,” and “Expansion tanks shall be sized in accordance with ASHRAE recommendations.” The IRC requires expansion tanks and has specific requirements for the capacity of an expansion tank to handle thermal expansion.<sup>488</sup> The language in the SRCC could be interpreted to not require an expansion tank if other design features allow for the thermal expansion of the heat transfer fluids.

6.1.1.4 Auxiliary Water-Heating Equipment. The SRCC states that “A backup system shall be provided such that the combined system will provide the same degree of reliability and performance as a conventional system.” The IRC states that every “dwelling shall have an approved automatic water heater or other type domestic water-heating system sufficient to supply hot water to plumbing fixtures and appliances intended for” [the typical uses].<sup>489</sup> The two requirements are functionally equivalent.

6.1.1.8 Vacuum-Induced Pressure Protection. The SRCC states that “All components of the solar energy system shall be protected against the maximum vacuum which could occur within the system.” The IRC states that “System components that may be subjected to pressure drops below atmospheric pressure during operation or shutdown shall be protected by a vacuum-relief valve.”<sup>490</sup> The language in the SRCC could be interpreted to not require vacuum relief valves if other design features allow for negative pressure in fluid loops.

6.1.1.10 Different Metallic Materials. The SRCC requires that “All metals used in the storage system which comes into contact with the heat transfer fluid shall be in accordance with . . . HUD Minimum Property Standard 4930.2.” This reference has not been reviewed for this report. The IRC requires that “Joints between different piping materials shall be made with a mechanical joint of the compression or mechanical-sealing

type. . . . Connectors or adapters shall have an elastomeric seal conforming to ASTM D 1869<sup>491</sup> or ASTM F 477.”<sup>492</sup> The intent of both requirements is likely comparable.

6.1.2.2 Protection from Ultraviolet Radiation. The SRCC states “Ultraviolet light shall not significantly alter the performance of any component or subcomponent of the system.” The only reference in the other codes to this topic is the requirement in the NEC that cabling rated for outdoor use is to be used for module connections in a PV system.<sup>493</sup> The SRCC requirement covers all system components and is more stringent.

6.1.3.1 Tank Design Requirements. The SRCC states that “Both pressurized and non-pressurized tanks shall meet the requirement set by a nationally accepted standard setting organization.” The IRC requires pressurized thermal storage tanks to be listed and labeled,<sup>494</sup> but there are no requirements for non-pressurized storage tanks in any of the codes. However, the general requirement that all plumbing appliances and components be labeled by an approved agency<sup>495</sup> makes the two sets of requirements comparable.

6.1.3.2 Tank Insulation. The SRCC requires that “tank insulation shall have a minimum of R-12 °F-ft<sup>2</sup>-h/Btu.” The IPC requires a water to air R-value of about R-9.7.<sup>496</sup> The SRCC requirements are more stringent.

6.1.5.3 Wiring Identification. The SRCC states that “Control circuit wiring and terminals shall be identified in accordance with Chapter 2 of the National Electrical Code.” This is obviously equivalent to the NEC requirements.

6.1.5.4 Temperature Rating. The SRCC states that “Wiring under insulation shall be rated for expected increased temperature conditions.” The NEC requires that “No conductor shall be used in such a manner that its operating temperature will exceed that designated for the type of insulated conductor involved.” Because high temperatures could be reached near collectors, but not necessarily under insulation, the NEC requirements are more restrictive.

6.1.5.5 Control Lines and Sensors. The SRCC states that all means of transmitting control or sensor signals “shall be sufficiently protected from degradation or from introducing false signals as a result of environmental or system operating conditions.” Several sections of the NEC and other codes require protection from physical damage for wiring and similar components. However, nothing in these codes guarantees the integrity of the control or sensor signals. The SRCC requirements are more restrictive.

6.1.5.6 Temperature Control. The SRCC states that “The system shall be equipped with a means for automatically limiting the temperature of the hot water at the fixtures to a selectable temperature” and has further requirements for the temperature range. The IPC has similar language, but no specific temperature range is described. The SRCC is more restrictive.

6.1.6.3 Insulation. The SRCC states that “All interconnecting hot water piping and the final 5.0 ft of the cold water supply pipe leading to the system, or the length of piping which is accessible if less than 5.0 ft, shall be insulated with R-2.6 °F-ft<sup>2</sup>-h/Btu or greater insulation.” The other codes have pipe insulation requirements for hydronic systems, but not for hot water heaters and similar installations. The SRCC requirements are more restrictive.

6.1.6.5 Water Shut-Off. The SRCC states the solar “system shall be valved to provide for shut-off from the service water supply without interrupting normal cold water service to the residence.” The IPC requires shut-off valves “On the water supply pipe to each appliance or mechanical equipment.”<sup>497</sup> This may not be strictly equivalent, but would likely be interpreted the same by local code officials.

6.2.5 Freeze Protection. The SRCC and the other codes have comparable general requirements for freeze protection. However, the SRCC has more specific requirements.

6.2.6 Protection from Leaks. The SRCC requires both the potable and non-potable sections of a solar system to be free from leaks “when tested in accordance with the codes in force at the installation site.” The IPC requires that the “system, or portion completed, shall be tested and proved tight under a water pressure not less than the working pressure of the systems. . . .”<sup>498</sup> The latter may not strictly require the testing of the non-potable sections of an SHW system. However, these would both likely be interpreted as equivalent by local code officials.

6.3.2 Protection of Electrical Components. The SRCC states that for electrical components “Overload and overcurrent protection . . . shall be consistent with the maximum current rating of the device and with the provisions of article 240, Chapter 2 of the National Electrical Code.” This is obviously equivalent to the requirements of the referenced NEC.

6.3.5 High Temperature Control. The SRCC states “Means shall be provided to limit tank temperatures to a value not to exceed the tank supplier’s specified high temperature limit. The pressure/temperature relief valve shall not be used for this purpose under normal operating conditions.” The IRC requires that water heaters need to be equipped with an energy cutoff device that limits tank temperatures to 210°F and that the device to implement this is in addition to the temperature and pressure relief valves. Because the maximum allowed tank temperature may be less than 210°F, the SRCC requirements are more stringent.

6.3.8 Contamination of Potable Water. The SRCC requires “Materials which come in direct contact with potable water shall not adversely affect the taste, odor or physical quality and appearance of the water. . . .” The IPC requires that “A potable water supply system should be designed, installed and maintained in such a manner so as to prevent contamination. . . .”<sup>499</sup> Contamination is defined as “An impairment of the quality of potable water that creates an actual hazard to the public health through poisoning or through the spread of disease. . . .”<sup>500</sup> The SRCC requirements are more stringent.

6.3.10 Backflow. The SRCC states that “Means shall be provided to prevent backflow of nonpotable fluids into the potable water system.” The IRC has more restrictive language, requiring an explicit backflow protection device for the potable water supply to a solar system.<sup>501</sup>

6.3.14 Liquid Flash Point. The SRCC requires “The flash point of a heat transfer fluid shall exceed by 50°F, or more, the design maximum no-flow temperature to be reached by the fluid in the collector.” The IRC requirement prohibits flammable gases and liquids from use as an SHW system heat-transfer fluid. Flammable liquids are defined as having “a flash point below 100°F.”<sup>502</sup> The flash point is “the minimum temperature . . .

at which the application of a test flame causes the vapors of a portion of the sample to ignite under “standardized test conditions.”<sup>503</sup> The flash point then is the minimum temperature at which the vapors from a liquid will ignite. Because the maximum heat-transfer-fluid temperature in an SHW system is higher than 100°F, the SRCC regulations are less strict than the IRC requirements.

6.3.16 Pressure Relief. The requirements for pressure relief valves in the SRCC and the other codes is comparable. The IMC further requires that the discharge piping “shall be of rigid pipe that is approved for the temperature of the system. The discharge pipe shall be the same diameter as the safety or relief valve outlet. Safety and relief valves shall not discharge so as to be a hazard, a potential cause of damage or otherwise a nuisance.”<sup>504</sup>

6.4.6 Maintenance and Servicing. The SRCC requires that system components “which may require . . . maintenance shall be easily and safely accessible by the owner and in accordance with the building codes in force at the installation site.” This is equivalent to the requirements in several of the other codes. Local code officials could interpret the other codes to require ladders, platforms, and guard rails to facilitate safe access. This would be much more stringent than the requirements in the SRCC.

6.5.5 Building Penetrations. The SRCC states that “Penetrations of the building through which piping or wiring is passed shall not reduce or impair the function of the enclosure.” This is comparable to various requirements in the other codes.

6.5.8 Structural Supports. The SRCC requires that “Neither wind loading (including uplift) nor the additional weight of filled collectors shall exceed the live or dead load ratings of the building, roof, roof anchorage, foundation or soil. Collector supports shall not impose undue stresses on the collectors. The design load shall be as specified by the codes in force at the installation site and shall include an additional load due to snow accumulation for applicable locations.” The intent here is to be at least as stringent as the requirements in the other codes. The first sentence is comparable to the requirements in the other codes except that it does not include the possible loads from other SHW system components, such as water storage tanks. There is also no discussion of the appropriate roof area to use when determining maximum allowable roof loads.

6.5.14 Pipe and Component Supports. The SRCC requirements for pipe hangers are comparable to the requirements of the other codes.

6.5.19 Penetrations Through Fire-Rated Assemblies. The SRCC requirements for penetrations through fire-rated assemblies are comparable to the requirements of the other codes.

---

<sup>486</sup> SRCC Document OG-300. Operating Guidelines and Minimum Standards for Certifying Solar Water Heating Systems: An Optional Solar Water Heating System Certification and Rating Program, April 1997

<sup>487</sup> SRCC 3.0 Regulations

<sup>488</sup> IRC 2303 Expansion tank

<sup>489</sup> IRC 3301.1 Required

<sup>490</sup> IRC 2701.2.4 Vacuum relief

<sup>491</sup> American Society for Testing and Materials D 869. Specification for Rubber Rings for Asbestos-Cement Pipe

---

<sup>492</sup> American Society for Testing and Materials F 477. Specification for Elastomeric Seals for Joining Plastic Pipe

<sup>493</sup> NEC 690-31 Methods permitted

<sup>494</sup> IRC 2701.3.2 Thermal storage units

<sup>495</sup> IPC 303.4 Labeled

<sup>496</sup> IPC 505.1 Unfired vessel insulation

<sup>497</sup> IPC 606.2 Location of shutoff valves

<sup>498</sup> IPC 312.5 Water supply system test

<sup>499</sup> IPC 608.1 General

<sup>500</sup> IPC 202 General definitions

<sup>501</sup> IRC 3402.4.3 Solar systems

<sup>502</sup> IMC 202 General definitions

<sup>503</sup> Ibid.

<sup>504</sup> IMC 1006.6 Safety and relief valve discharge

## 6.0 Appendix B

### **ASHRAE Standard 90.2 Energy-Efficient Design of New Low-Rise Residential Buildings and Energy Credit for Renewable Energy and Energy-Efficient Technologies**

The ASHRAE Standard 90.2 (90.2) involves the same issues as the IECC. Like the IECC, 90.2 includes both prescriptive and performance compliance paths. The subject of this Appendix is the impact of the 90.2 performance path on the PV and solar thermal technologies discussed in the main body of this report.

A major difference between the IECC and 90.2 performance paths is that the latter is based on the cost of energy, not just the energy involved.<sup>505</sup> This allows economically justifiable building design decisions to be supported by 90.2 rather than denied by the IECC compliance path.

Like the IECC, the 90.2 compliance path involves the analysis of a prescriptive design and a proposed design.<sup>506</sup> The prescriptive design must comply with the requirements of the 90.2 prescriptive path.<sup>507</sup> With some restrictions, the proposed design is modeled as it is to be built and operated.<sup>508</sup>

In this discussion of the impacts of the 90.2 performance path requirements on each technology, terms like “credit is allowed” means that the prescriptive path allows the energy savings from the technology to be included in the analysis.

The 90.2 performance path precludes credits for many technologies. “Annual energy cost compliance is applicable to energy for space conditioning only. Energy for other uses, such as domestic hot water, cooking, lighting, and appliances, is included for total energy cost estimates, but is not a variable between the proposed design and prescriptive design for compliance with this standard. . . . Although space-conditioning, domestic hot water heating, and appliance energy costs are calculated together, no compliance trade-offs are allowed between them.”<sup>509</sup> This language appears to preclude credit for RE sources that service other than space heating loads. However, “The analysis of the proposed design shall take into account all qualities, details and characteristics of the design that significantly affect energy use and cost. These may include construction, geometry, orientation, exposure, materials, equipment, and RE sources.”<sup>510</sup> A reasonable interpretation of this is that RE sources can be credited toward the annual energy cost, but loads other than space conditioning cannot be changed between the prescriptive and proposed designs.

Credit for PV systems in buildings, building-integrated PV systems, and SHW systems for domestic hot water and space-heating is allowed if it can be adequately modeled with the chosen analysis tool.

### **6.1 Photovoltaic Systems in Buildings and Building-Integrated Photovoltaic Systems.**

Credit is allowed if it can be adequately modeled with the chosen analysis tool.

### **6.2 Active Solar Domestic Hot Water and Space-Heating Systems.**

Credit is allowed if it can be adequately modeled with the chosen analysis tool.

### **6.3 Passive Solar and Low-Energy Design**

Passive solar residential building design involves energy efficiency, solar-oriented glazing, and thermal mass. Low-energy design generally combines passive solar concepts and low air infiltration with very highly insulated and possibly highly massive buildings. Very low-energy kitchen and other appliances and low-flow water fixtures are often included in passive solar or other low-energy building designs.

The energy efficiency issues of innovative envelopes and glazing are not addressed in this section. These topics are discussed in the main body of this report.

Energy credit for these technologies are generally allowed in the 90.2 performance path.

Passive solar design strategies that may be impacted by PV or solar thermal systems and are included in 90.2 are discussed in this section.

#### **6.3.1 Glazing Area, Orientation, and Shading**

The requirements for the prescriptive design may not allow a geometrically correct model. “The total vertical fenestration area of the prescriptive design shall be equal to the total fenestration area of the proposed design (including skylights) or prescriptive glazing allowance, whichever is less. The prescriptive glazing allowance is 18% of the floor area or 125 ft<sup>2</sup> per living unit, whichever is greater. One-fourth of the fenestration area shall be located vertically on each orientation. The prescriptive design shall have no skylights.”<sup>511</sup> These window area and orientation requirements provide for the energy advantages of the proposed design windows, as long as the latter are well designed.

If passive solar heating is included in the analysis, the analysis tool must include the effects of self shading and external shading.<sup>512</sup> Self-shading is from the building itself; external shading includes permanent existing landscape features.<sup>513</sup> “Walls and windows of the prescriptive design shall be considered to have no self external shading, except any external shading modeled for the proposed design shall be modeled for the prescriptive design.”<sup>514</sup> Note that this excludes self-shading from the prescriptive design. These requirements allow for the effects of shading in the analysis.

The internal shading characteristics for the prescriptive design is specified.<sup>515</sup> Improved internal shading systems are allowed in the proposed design.<sup>516</sup>

### **6.3.2 Thermal Mass**

The specified internal thermal mass for the prescriptive design is 8 lb/ft<sup>2</sup> of the conditioned floor area for furniture and contents and 5 lb/ft<sup>2</sup> for interior walls.<sup>517</sup> “The proposed design with nonstandard construction features may use a different structural mass assumption if detailed calculations are documented.”<sup>518</sup> There is no discussion of the thermal mass of exterior walls, but these are presumably allowed as well.

### **6.3.3 High-efficiency Equipment, Appliances, and Water Use**

The same internal gains, domestic hot water use and occupant energy use are required for both the prescriptive and proposed designs.<sup>519, 520, 521</sup> The potential energy savings from these technologies are not allowed.

## **6.4 Innovative Roof/Attic, Wall, Floor and Foundation Systems**

### **6.4.1 Components with High R-value**

Credit is allowed if it can be adequately modeled with the chosen analysis tool.

### **6.4.2 Components for High Thermal Mass**

Credit is allowed if it can be adequately modeled with the chosen analysis tool.

### **6.4.3 The Ground as Thermal Mass**

“The prescriptive design shall have the same foundation type and floor constructions with the same fraction of each construction as the proposed design. . . . All floor conditions in the prescriptive design house shall be constructed and modeled in a manner consistent with that of the proposed design except that the prescriptive design shall meet the requirements of Section 5.”<sup>522</sup> Section 5 describes the prescriptive requirements for below grade surfaces. This means that, for example, a bermed proposed design needs to be compared to a bermed prescriptive design. However, the insulation details of the proposed design can be different to take advantage of the thermal mass of the soil. Credit for any energy savings from such analysis is allowed.

### **6.4.4 Components that Modify Solar Radiation**

“Since colors are subject to change over the life of the building, the exterior absorptivity of all exterior walls and roofs shall be 0.5 regardless of color.”<sup>523</sup> This requirement disallows energy credit for exterior colors. The issues of selective surfaces or “smart” surfaces is not addressed, but would also not be allowed by this requirement.

### **6.4.5 Less-expensive Wall Systems**

Credit is allowed if it can be adequately modeled with the chosen analysis tool.

#### **6.4.6 Components that Reduce Air Infiltration**

Infiltration rates for the prescriptive and proposed design are identical unless a blower door test is performed after construction is completed.<sup>524</sup> Because the infiltration rates cannot easily be changed after the building is complete, the safe assumption for reaching compliance is that the infiltration rate for the two designs is identical. This does not allow energy credits for this technology.

### **6.5 Innovative Fenestration Systems or Products**

The requirements for glazing area, orientation, and shading and solar heat gain coefficients for the standard design glazing are discussed in the previous section on passive solar

Innovative fenestration systems or products include glazing with improved thermal resistance, improved or application tailored optical properties, and a variety of possible technologies that change the thermal or optical properties. Credit is allowed for these technologies, if they can be adequately modeled with the chosen analysis tool.

### **6.6 Innovative Heating, Ventilation, and Air Conditioning (HVAC) Systems.**

#### **6.6.1 Higher-efficiency Equipment**

The language for higher efficiency equipment in the proposed design is difficult to understand. However, it implies that the prescriptive design must use HVAC equipment with the minimum prescriptive efficiency requirements.<sup>525</sup> The introduction to the Proposed Design requirements states that the details and characteristics of the equipment in the proposed design is to be included in its analysis.<sup>526</sup> This allows credit for higher efficiency equipment if it can be adequately modeled with the chosen analysis tool.

#### **6.6.2 Equipment with Part-load Curves Tailored to Real-world Load Histograms**

Credit is allowed for this technology if it can be adequately modeled with the chosen analysis tool.

#### **6.6.3 Improved Control Strategies, including Smart or Adaptive Controls**

Credit is allowed for these technologies if they can be adequately modeled with the chosen analysis tool. However, the thermostat settings for the prescriptive and proposed designs shall be the same.<sup>527</sup> This precludes credit for any control strategies that would affect zone setpoints or schedules.

#### **6.6.4 Variable Speed Fans or Pumps**

Credit is allowed for these technologies if they can be adequately modeled with the chosen analysis tool.

#### **6.6.5 High-efficiency Motors**

Credit is allowed for these technologies if they can be adequately modeled with the chosen analysis tool.

#### **6.6.6 Mechanical Ventilation**

“If the proposed design has a mechanical outdoor air ventilation system, the prescriptive design shall have a similar system meeting the prescriptive requirements and supplying the same air quantity.”<sup>528</sup> This allows technologies like air-to-air heat exchangers and economizers, which always introduce at least the minimum required outside air flow. However, CO<sub>2</sub> sensor control for ventilation air is not allowed because less than the required prescriptive air quantity is introduced when the occupancy level is low.

#### **6.6.7 Evaporative Cooling**

If evaporative cooling is used in the proposed design, it must also be used in the prescriptive design.<sup>529</sup> This precludes credit for these technologies.

#### **6.6.8 Multiple Zoning in Buildings**

“The prescriptive design shall have one thermal zone.”<sup>530</sup> Generally, the proposed design can have two thermal zones.<sup>531</sup> This may not be adequate to capture the energy impacts of a multi-zone HVAC system.

#### **6.6.9 Ground-source Heat Pumps**

If a ground-source heat pump is used in the proposed design, it must also be used in the prescriptive design.<sup>532</sup> This precludes credit for these technologies.

#### **6.6.10 Gas-cooling, including Engine-driven Heat Pumps and Absorption Cooling**

“The same fuel source shall be used in the proposed design and the prescriptive design.”<sup>533</sup> This precludes credit for these or other fuel-switching technologies.

### **6.7 Electrical Lighting, Daylighting, and Associated Controls**

“Energy for . . . lighting . . . is not a variable between the proposed design and prescriptive designs for compliance with this standard.”<sup>534</sup> This precludes credit for lighting or daylighting technologies.

## **6.8 Innovative Thermal Storage Systems**

The language is confusing on this technology. On the one hand, "Equipment of the same DOE product class shall be used in the proposed design and prescriptive design."<sup>535</sup> This implies that thermal storage may need to be included in both designs. On the other hand, "The compliance path provides an opportunity to account for the benefits of innovative... designs, such as . . . thermal storage."<sup>536</sup> Because the language accounts for the benefits of such innovations, it presumably allows the proposed design to include thermal storage while the prescriptive design does not.

## **6.9 Buildings Requiring No Heating/Cooling Equipment**

There do not appear to be explicit requirements in either the prescriptive or performance paths that require heating or cooling equipment. The prescriptive path provides requirements for minimum efficiency levels for various types of HVAC equipment.<sup>537, 538</sup> However, there is no language in the prescriptive path that requires the installation of such equipment. In the performance path, when calculating the annual energy cost "for both the prescriptive design and the proposed design, all conditioned spaces shall be maintained at the specified thermostat setpoints at all times except for minor deviations at thermostat setup and setback and when outdoor conditions exceed normal design conditions. . . . If equipment to meet a load is not included in the design, such equipment shall be assumed in the calculations and its energy cost included. In no case shall the annual energy cost of the proposed design be reduced by not conditioning its space."<sup>539</sup> Also, "Equipment of the same DOE product class shall be used in the proposed design and prescriptive design."<sup>540</sup> This seems to imply that there are no requirements for heating and/or cooling systems in buildings. However, no energy credit is allowed for not having such equipment in the building.

## **6.10 Buildings Requiring No Conventional Air Distribution (Duct) Systems.**

There are no requirements for ducts in the performance path. "Ducts in the prescriptive design, if any, shall be assumed to be completely in conditioned spaces."<sup>541</sup> Presumably, if the proposed design does not include ducts, then neither does the prescriptive design. Therefore, energy credits for this technology are not allowed.

## **6.11 Solar-Assisted Ventilation Systems.**

Credit is allowed for this technology if it can be adequately modeled with the chosen analysis tool.

## **6.12 Desiccant Dehumidification Systems**

Credit is allowed for this technology if it can be adequately modeled with the chosen analysis tool. Simultaneous analysis of building loads and the impact of a desiccant dehumidification system can be done with TRNSYS.<sup>542</sup> Unfortunately, TRNSYS is designed as a research tool and is not appropriate or cost-effective for the analysis of each intended installation.

---

<sup>505</sup> 90.2 8.1 Purpose

<sup>506</sup> Ibid.

<sup>507</sup> 90.2 Chapters 5, 6 and 7

<sup>508</sup> 90.2 8.4 General

<sup>509</sup> 90.2 Scope

<sup>510</sup> 90.2 8.6 Proposed Design

<sup>511</sup> 90.2 8.7.7 Fenestration

<sup>512</sup> 90.2 8.6.4 Shading

<sup>513</sup> Ibid.

<sup>514</sup> 90.2 8.7.9 Shading

<sup>515</sup> 90.2 8.8.3.2 Window Management

<sup>516</sup> Ibid.

<sup>517</sup> 90.2 8.8.2 Internal Thermal Mass.

<sup>518</sup> Ibid.

<sup>519</sup> 90.2 8.8.1 Internal Heat Gains.

<sup>520</sup> 90.2 8.9.3 Energy Consumption.

<sup>521</sup> 90.2 8.10 Occupant Energy Use.

<sup>522</sup> 90.2 8.7.8 Floors and Foundation Type.

<sup>523</sup> 90.2 Exterior Absorptivity.

<sup>524</sup> 90.2 8.8.3.4 Infiltration.

<sup>525</sup> 90.2 8.8.4.4 Equipment Efficiency.

<sup>526</sup> 90.2 8.6 Proposed Design.

<sup>527</sup> 90.2 8.8.4.7 Thermostat Setpoints.

<sup>528</sup> 90.2 8.8.4.3 Mechanical Ventilation.

<sup>529</sup> 90.2 8.8.4.1 General. This requires the same class of equipment for both designs.

<sup>530</sup> 90.2 8.8.4.2 Zoning.

<sup>531</sup> Ibid.

<sup>532</sup> 90.2 8.8.4.1 General. This requires the same class of equipment for both designs.

<sup>533</sup> Ibid.

<sup>534</sup> 90.2 8.2 Scope.

<sup>535</sup> 90.2 8.8.4.1 General.

<sup>536</sup> 90.2 8.1.1 Compliance.

<sup>537</sup> 90.2 6.4.3 Furnaces and Boilers.

<sup>538</sup> 90.2 6.4.3.3 Air Conditioners, Electrically Driven, for example.

<sup>539</sup> 90.2 8.8.4.7 Thermostat Setpoints.

---

<sup>540</sup> 90.28.8.4.1 General.

<sup>541</sup> 90.2 8.7.1 Ducts.

<sup>542</sup> Klein, S., and Beckman, W. 1994. TRNSYS: A transient simulation program. Engineering Experiment Station Report 38-14. University of Wisconsin, Madison.

## 7.0 Appendix C

### Suggestions for Code Changes

This Appendix compiles a number of specific language changes for the various codes, which could be made to allow a more fair treatment of EE and RE technologies. Other suggested code changes in the report are not included here; for example, the development of sections that accumulate all of the code requirements and references to other sections for a technology in one location.

**IECC 402.1.2.1 Opaque surface U-values.** The real U-values for the opaque surface assemblies shall be used in the proposed design.

**IECC 402.1.2.11 External surface optical characteristics.** The surface solar absorptivity and thermal emissivity for the roof and exterior walls shall be 0.7 and 0.9, respectively, in the Standard design.<sup>543, 544</sup> If known, real surface characteristics shall be used for the Proposed design. Otherwise, the Standard design values shall be used for the Proposed design.

**IECC 402.1.3.1.1 Orientation, Standard design.** The standard design shall have equal glazing areas, including glass doors, for walls facing any of the following directions: north, east, south and west.

**IECC 402.1.3.1.5 Interior shading, Standard design, and Proposed design.**

**Exception 2.** If the Proposed design has windows or controlled shading systems, which produce significantly different shading behavior than typical windows and shades, the real shading behavior can be used in the proposed design energy model.

**IECC 402.1.3.3 Thermal mass.** The standard design shall have a mass value for furnishings of 8 lb/ft<sup>2</sup> of floor area. The structural mass for the Standard design shall be the actual mass of appropriate lightweight wall construction or other constructions required in this Chapter. The structural mass for the Proposed design shall be the actual mass of the construction in this design.

**IECC 402.1.3.4.3 Exception.** Glass doors or the glazed areas of opaque doors shall be treated as fenestration by this chapter of the IECC and shall meet all requirements for glazing. The opaque areas of the doors shall meet the above requirements.

**IECC 402.1.3.5 Heating and cooling controls Exception. Multiple zone HVAC systems.** If HVAC systems with multiple zone capabilities are installed, then the actual number of zones and their unique thermostat and other schedules shall be used in the analysis of the proposed design.

**IECC 402.1.3.5.1 Advanced control strategies in the Proposed design.** HVAC system-related control parameters, setpoints, and algorithms shall be modeled as realistically as possible by the analysis tool.

**IECC 402.1.3.5.2 Humidification controls.** If desiccant or other dehumidification equipment is included in the proposed design, the minimum and maximum humidity setpoints shall be 30 and 60 percent, respectively, for both the standard and proposed designs. The standard design mechanical system shall be capable of maintaining the maximum humidity setpoint.

**IECC 402.1.3.6.1 Real internal gain levels for the proposed building.** Internal gain levels and schedules based on the actual installed lighting power densities, appliances, and number of occupants can be used to comply with the requirements of this chapter. Lighting, appliance, equipment, and occupant schedules can be taken from an appropriate source. Occupant-related heat gains must be taken from the ASHRAE Handbook of Fundamentals. (Note that an appropriate source is not specified.)

**IECC 402.1.3.7.1 Water heater efficiency.** The efficiency for the domestic hot water heater for the Standard design shall be found on IECC Table 504.2. The efficiency for the domestic hot water heater for the Standard design shall be the actual efficiency of the proposed equipment.

**IECC 402.1.3.10 Air infiltration.** No energy credit shall be granted for ACH levels below 0.35 ACH unless heat recovery is applied to the intake and exhaust air streams. The energy credit is then based on the heat-exchanger air-flow rate multiplied by its sensible heat-recovery effectiveness. If heat recovery or other mechanical ventilation is installed, the infiltration rate shall be zero for all times when the mechanical ventilation is causing positive pressure in the building.

**IECC 402.1.3.10 Air infiltration Exception 1. Mechanical ventilation.** If mechanical ventilation systems are present, air-flow rate measurements of the supplied ventilation air can be used to calculate the air-change rate used in the proposed design.

**IECC 402.1.3.10 Air infiltration Exception 2. Heat recovery.** If heat recovery is installed between the ventilation air and exhaust air ducts, the allowable energy credit shall be based on the measured air flow rates and the effectiveness of the heat exchanger. Sensible energy transfer is allowed for heating, and both sensible and latent energy transfer is allowed for cooling.

**IECC 402.1.3.10 Air infiltration Exception 3. CO<sub>2</sub> sensors.** If CO<sub>2</sub> sensors are installed, they shall be calibrated to allow 0.35 ACH of ventilation air flow when the building is fully occupied with two people for the first bedroom and one person for other bedrooms. The ventilation air flow rate shall then be allowed to fall below this rate during periods of reduced occupancy. In the analysis of the proposed design, reasonable schedules for occupancy and the ventilation air flows shall be used to provide proper credit for this technology.

**IECC 402.1.3.11 Solar access.** Any existing permanent objects, which will reduce the solar gains on any window surfaces or other solar energy collection devices, must be accounted for in the energy analysis.

**IECC 402.1.4 Foundation walls.** If the R-value is accounted for in the analysis, the thermal mass effects of the soil shall also be permitted in the analysis of the standard and proposed designs.

**IECC 403.1.5 Solar hot water energy exclusion.** Thermal energy from solar hot water systems shall be permitted to be excluded from the total energy consumption allowed for the building. This thermal energy must be used in the building to displace purchased electrical energy, fuel, or other thermal energy used for space heating of hot water.

**IECC 403.1.5 Daylighting systems energy exclusion.** Lighting energy savings from daylighting systems are permitted. Daylighting apertures are excluded from the requirements of Sections 403.1.1.2 and 403.1.2.2. Energy savings from daylighting systems shall be calculated according to the methods in Section 402, except that any requirements for exterior shading or the orientation of the glazing in Sections 402.1.3.1 and 403.1.3.2 are not applicable. The analysis must use reasonable hourly internal gain schedules for the standard design electric lighting loads. These can be taken from an appropriate source. (Note that an appropriate source is not specified.)

**IECC 402.3.2 Simulation details.** The calculation procedure used to simulate the operation of the building and its service systems through a full-year operating period shall be detailed to permit the evaluation of the effect of system design, climatic factors, operational characteristics, and mechanical equipment on annual energy usage. Manufacturer's data or comparable field test data shall be used when available in the simulation of systems and equipment. The calculation procedure shall be based upon 8,760 hours of operation of the building and its service systems and shall utilize the design methods specified in the ASHRAE Handbook of Fundamentals.

**IECC 402.3.2.1 Special requirements for appropriate energy analysis tools.** If the proposed design involves significant amounts of thermal mass and contains thermal control systems with non-linear control characteristics, then a true 8,760-hour annual simulation driven by appropriate weather data shall be used in the systems analysis.

**IECC 402.3.2.2 Hourly simulation tools for photovoltaic system analysis.** If the proposed design involves a PV system to generate electricity, then a true 8,760-hour annual simulation driven by appropriate weather data shall be used in the systems analysis. This simulation shall be capable of analyzing the type of PV system specified in the design. This analysis shall use the hourly electrical loads from the building simulation as the basis for the analysis of the PV system.

**IECC 503.2.2 Exception for equipment with improved part-load energy efficiency.** Heating and cooling equipment designed for improved part-load EE shall comply with this code if testing to appropriate standards (or recognized engineering analysis) shows annual performance equal to or higher than the appropriate requirements in Table 503.2.

**IECC 403.1.4 Photovoltaic energy exclusion.** Electrical energy from solar PV systems shall be permitted to be excluded from the total energy consumption allowed for the

building. This electrical energy must be used in the building to displace purchased electrical energy.

**IECC 503.2.1 Exception for equipment as part of thermal storage systems.** Heating and cooling equipment that are parts of thermal storage systems shall comply with this code if testing to appropriate standards (or recognized engineering analysis) shows annual performance equal to or higher than the appropriate requirements in IECC Table 503.2.

**IRC 308.8.2 Permitted materials.** Laminated glass with a minimum 0.015-in. polyvinyl butyral interlayer for glass panes 16 ft<sup>2</sup> or less in area; for larger sizes, the minimum interlayer thickness shall be 0.030 inch. Alternate materials can be used for the interlayer if it provides comparable performance as confirmed by testing under an appropriate standard. (Note that the appropriate standard is not now identified.)

**IRC 1401.4.1 Sizing of heating and cooling equipment for thermal storage systems.** The capacity for heating and cooling equipment that is part of thermal storage systems shall allow a credit for the heating and cooling capacities from the storage subsystems.

**IRC 2701.2.5.1 Acceptable freeze protection methods.** Freeze protection shall be provided by heating, insulation, suitable low-freezing-point fluids, draining of piping and other components, or an appropriate combination of these methods.

**IRC 2701.2.6.1 Exception.** Non-pressurized, draining, solar hot water systems do not need expansion tanks if the system is designed to accommodate the expansion volumes under “Nonpressurized Type” in IRC Table 2302.2.

**IRC 2701.3.2.1 Thermal storage unit insulation levels.** Thermal storage units shall be insulated so that heat loss is limited to a maximum of 15 BTH/h/ft<sup>2</sup> of external tank surface area. For design purposes, the design ambient temperature shall not be higher than 65°F. This equates to a minimum water to air R-value of about 9.7.

**IRC 3301.7 Locations significantly above sea level.** The maximum temperature for the energy cutoff device shall be 2°F below the local boiling point of water.

**IRC 303.6.1 Exception. Heating not required.** Heating systems are not required if hourly thermal analysis, performed as described in Chapter 4 of the IECC, shows that the minimum required room temperature defined in 303.6 is maintained for every conditioned building zone for every hour of the analysis year with an ambient temperature at or above the winter design heating temperature in Table 301.2a of this Code. This requires that the analysis method performs a true hourly energy analysis, can model simultaneous multiple zones, and can produce outputs for the hourly zone and ambient temperatures. The modeling of a single, mixed-air temperature for each zone is sufficient to meet these requirements. The weather data used to drive the simulation must have statistically correct values for and numbers of extreme ambient temperatures.

**IRC 3402.4.3.1 Exceptions for solar systems that do not require backflow protection.** Solar systems that do not expose potable water to non-potable water are exempt from the requirements of 3402.4.3. This includes solar systems where the potable water acts as the solar loop heat-transfer fluid, where the solar loop fluid is essentially non-toxic, and where contamination of the potable water is not possible.

Presently, the relevant code language applicable to PV systems is spread throughout the various codes. The IRC should include a new chapter for PV systems. This allows practitioners in the PV field to easily locate all applicable code requirements. This new chapter should include references to the NEC Article 690, and other relevant language in the IRC, IMC, NEC, and IECC.

Presently, the relevant code language applicable to solar hot water systems is spread throughout the various codes. The IRC should include a revised chapter for solar hot water systems. This allows practitioners in the SHW field to easily locate all applicable code requirements. This new chapter should include the present language in the IRC Chapter 27 and the IMC Chapter 15 and references to the other relevant language in the IRC, IMC, IPC, NEC, and IECC.

---

<sup>543</sup> These values are used as the defaults in the DOE2.1E program. They are representative of a wide range of painted and other types of surfaces.

<sup>544</sup> Winkleman, F., et. al. 1993. DOE-2 BDL Summary. Lawrence Berkeley Laboratory.

## 8.0 Appendix D

### Suggestions for Potential Research Areas

Several potential research topics were identified in this report. These are presented here.

1. **Wind loading of roof-top PV panels and Solar Hot Water (SHW) collectors.** IRC Table 804.3.3b presents the information needed to convert the wind speed to an equivalent snow load. In this Table, steeper sloped roofs have a higher equivalent snow load than shallower ones with the same design wind speed and exposure. There are potential implications here for roof mounted systems with steeper slopes than the supporting roof structure. Guidelines need to be developed for appropriate roof rack structural loads and appropriate designs for different locations.
2. **Structural requirements for PV shingles.** Several sections on asphalt shingles cover the types and numbers of needed fasteners in typical and high wind areas, how the underlayment is applied, protection against ice buildup and the proper installation of flashings. Identical requirements may apply to PV shingles. However, the different physical characteristics of PV and asphalt shingles may require changes in or additions to the requirements of IRC Section 905 when applied to PV shingles. This is an area of possible research for DOE or an interested standards or manufacturer's organization.
3. **Access and safety issues of roof-top PV and SHW panels and other equipment.** The enforcement of access and safety codes as applied to PV systems could provide major economic and architectural obstacles to the widespread implementation of this technology. Permanent ladders, railings, access space between panels, and similar constraints could be imposed on roof-top mounted systems. It must be remembered that these requirements arose from real safety issues during the maintenance of mechanical systems. The problem for the PV industry is to include language in the codes that specifically exempt their systems from these requirements or to otherwise provide data that will convince local code officials that these requirements are unnecessary.
4. **Calculating proper roof dead loads for SHW systems.** Some designs of active SHW systems, such as those with a roof-located water storage tank, can produce highly concentrated roof loading. Higher weights are more likely to reach the roof dead-load limitations of 15 PSF (and 9 PSF in seismic areas). While calculation of the maximum weight of these systems is relatively easy to determine, the applicable area is not. The roof structure needs to be designed and built to prevent both general and local failure. Loads over small areas need to be solidly supported and the structure must transmit the resulting loads to its supporting structural elements. If active SHW systems are installed on existing or new buildings, the roof structure may need to be evaluated to determine if excessive loading is a problem. Guidelines for the proper approach to this issue may be an appropriate area for research.

5. **Changing the orientation of windows.** Moving windows to take advantage of passive solar gains changes the glazed fractional area of the various walls. Compliance with any of the four prescriptive requirement sections in the IECC are all affected by this fractional glazed area.

- Compliance by performance on an individual component basis. The overall maximum allowed U-value for each wall, as calculated by a standard one-dimensional parallel path formula, must not exceed the values in IECC Figure 502.2(1). These maximum U-values are a function of the heating-degree-days, with different functions for one- and two-family dwellings or a building with three or more dwellings. Because windows usually have higher U-values than opaque walls, increasing the glazed fraction on, for example, the south wall requires higher insulation levels for that wall.
- Compliance by total building envelope performance. The U-values for individual components can exceed those required above if the overall heat-loss coefficient for the entire building envelope is less than or equal to that for a building with the same geometry that meets the individual component requirements. This allows solar tempering, or the moving of windows to the south side, without increasing the building total glazed area, because the total building heat loss coefficient does not change. If the glazed area is increased so that, for example, the south wall does not meet the individual component requirements, the U-value of other components can be modified to bring the entire envelope into compliance.
- Compliance by prescriptive specification on an individual component basis. This alternate path contains minimum insulation R-value compliance requirements for walls and other surfaces based on the building's glazing percent of the total wall area. There are separate tables for a maximum of 8%, 12%, 15%, 18%, 20%, and 25% for one- and two-dwelling buildings. The requirements for buildings consisting of more than two dwellings are presented in tables for maximum glazing percentages of 20%, 25%, and 30%. All of the tables have minimum insulation R-values based on the heating-degree days. Values are also presented for the maximum allowed glazing U-value for each glazing percentage and heating-degree day. Less work is needed to determine compliance with this path, because only the window U-values; the percent glazing; and the wall, ceiling, floor, basement, slab and crawl-space insulation R-values need to be considered. These tables are only applicable to wood construction. The window area used includes all skylights, above-grade windows, and basement windows if the basement is conditioned, less one percent. There is no obvious explanation why 1% of this window is excluded. The applicable window area is the rough opening area.

It is likely that these compliance paths are not equivalent for all locations and building designs. A simulation based research effort doing building simulations by DOE or other interested groups could determine the easiest path to take for compliance.

6. **Determining appropriate solar heat gain coefficient limits for glazing in different orientations.** There are restrictions for the solar heat gain coefficient for areas with less than 3500 heating-degree days. The area-weighted average solar heat gain coefficient for all glazing, including shading effects, must be less than 0.4. The purpose here is to decrease excessive heat gains to reduce cooling loads. However, the impacts on cooling loads are greater for south- or west-facing windows than for other orientations. Directional heat gain coefficient limits may be another area for DOE research.
7. **Determining appropriate prescriptive requirements for massive walls.** The prescriptive path gives credit for exterior walls with specified thermal mass by increasing the allowed wall U-value. If the wall thermal mass is at least 6 Btu/ft<sup>2</sup>/°F, IECC Tables 502.1.1(1) through (3) are applicable. The three tables are for exterior insulation, interior insulation, and insulation mixed through the thickness of the wall, as in a log home. The basis for these credits is not clear. There is no different criteria for walls that receive solar gains and those that do not. DOE may be interested in pursuing research into if whether these criteria are reasonable and appropriate values for the corrections if passive solar energy is considered.
8. **Development of guidelines for the structural requirements of atypical wall constructions.** Using innovative wall-insulation strategies may require changes in the structure of components. Structural considerations for wood- or metal-frame walls are thoroughly covered in the codes. Limitations for wall heights and stud spacing for 2x4 and 2x6 wood and metal walls are presented. Other wall constructions that could be used to allow more thickness for the installation of insulation are not considered. These types of walls, including for example, staggered 2-by studs that do not bridge the gap between the interior and exterior facings, would presumably need to be individually engineered to satisfy local code officials. Structural foam panels are also not considered in these code sections. These development of structural guidelines for atypical wall constructions could be areas of interest for DOE research.
9. **Guidelines for the accurate analysis of high thermal mass buildings and components.** The IECC performance path does not allow an accurate accounting for the effects of thermal mass. This can produce inaccurate analysis results and may bias against building designs with high mass components. This is an appropriate area for DOE-sponsored research.
10. **Guidelines to reduce overheating for designs with innovative glazing, shading, and other features.** In the prescriptive path, for locations with heating-degree days less than 3,500, the combined solar heat gain coefficient (the area weighted-average) of all glazed fenestration products (including the effects of any permanent exterior solar shading devices) in the building shall not exceed 0.4. The purpose here is to reduce heat gains during cooling periods. It is not clear how code officials might interpret this in regards to switchable glazing or other possible controllable glazing strategies. There is no consideration in the prescriptive path given to other methods

of reducing excessive solar gains, including exterior or interior shading. The solar heat gain coefficients also do not consider the variations in solar climates found in different locations. The entire area of optimizing glazing and shading designs for passive solar performance and prevention of overheating could be a DOE research project. Guidelines for designs appropriate for different locations could be developed.

11. **Appropriate sizing of HVAC equipment for buildings with atypical controls, thermal mass, energy storage, and other features.** Heating and cooling equipment shall be sized according to ACCA Manual J. These sizing requirements should be reviewed, particularly in regards to buildings with high thermal mass, setbacks, or other control strategies that may impact the real peak HVAC loads that must be satisfied. Oversizing of HVAC equipment is typical in residential construction. This leads to equipment operating at low part loads most of the time, with a resulting loss in annual average efficiency. A study analyzing the degree of oversizing that is typically found in real installations and the energy implications of this practice would be a reasonable research project for DOE to pursue.
12. **Development of prescriptive measures for HVAC equipment with atypical part-load efficiency curves.** Heating and cooling equipment designed for improved part-load EE shall comply with this code if testing to appropriate standards (or recognized engineering analysis) shows annual performance equal to or higher than the appropriate requirements in IECC Table 503.2. An activity of DOE or other interested parties could be to develop a standard to test and calculate appropriate equivalent performance factors for this atypical heating and cooling equipment.
13. **Identification or development of an approach to quantify daylighting savings for prescriptive path compliance.** Many of the hourly simulation tools that would be applicable to perform the performance path analysis may not be capable of the daylighting analysis. Among other requirements, the analysis tool must be capable of tracking and reporting electrical energy use, as well as heating- and cooling-related energy use. Because daylighting is very specific to building design and location, the development of an accurate simplified approach may be difficult or impossible. DOE could look into this possibility, with the goal of developing appropriate tables or maps to be used for prescriptive path compliance.
14. **Development of a methodology to provide proper sizing for thermal storage system components.** The heating or cooling capacity for thermal storage systems is typically larger than the capacity of the furnace/boiler or chiller. These systems can be designed to provide heating/cooling from both the storage system and heater/cooler during extreme conditions. This total capacity may not be recognized as meeting the sizing requirements of the IRC. A methodology needs to be developed to determine the appropriate energy rate capacity for different thermal storage system designs.

15. **Development of guidelines for accounting for radiant effects in high-mass buildings.** A special situation can occur for high thermal-mass passive-solar buildings. In these buildings, the radiant heat from the wall surfaces may maintain comfortable zone conditions even if the dry bulb air temperature drops below 68°F. Local code officials are not likely to accept this subtlety. Guidelines in this area could be an area for research by DOE.
16. **Investigation into the impact of weather data on equipment sizing and interior temperatures during design outdoors conditions.** The interior temperatures of building with no heating or cooling equipment is sensitive to the choice of design weather data. A potential DOE activity is to determine the appropriateness of TMY or other weather data sources for this analysis.
17. **Development of guidelines and tools for the analysis of buildings with significant interior radiant temperature effects.** Passive solar buildings that maintain comfort without necessarily maintaining the 68°F temperatures required by the codes need to be analyzed with analysis tools that can model the interior radiant environment. Not all of the tools that would otherwise be appropriate for the performance path analysis can do this. DOE could publish a guideline as to which tools are acceptable and how they should be used to correctly model these effects and report the appropriate output variables.
18. **Development of analysis tools to integrate the impact of transpired collectors on building wall loads and mechanical system performance.** The energy impact of transpired collectors could be determined under the analysis procedures in the performance path. However, this requires analysis software that can model both buildings and this technology. Appropriate software does not presently exist, except possibly in the research community. Development of software with this capability would aid in the design and implementation of the technology. It is possible that existing energy analysis programs could be modified with the additional capabilities to model this technology. However, the various aspects of this technology (as solar collectors, a wall layer, and part of the mechanical system) would make this a reasonably involved process. In particular, the changing effective wall U-value during operation of the transpired collectors is likely beyond the capabilities of DOE2 or other similar programs. This is an activity the DOE could pursue to aid in the more widespread application of this technology.
19. **Wind loading of roof-top PV panels and SHW collectors.** IRC Table 804.3.3b presents the information needed to convert the wind speed to an equivalent snow load. In this table, steeper-sloped roofs have a higher equivalent snow load than shallower ones with the same design wind speed and exposure. There are potential implications here for roof-mounted systems with steeper slopes than the supporting roof structure. Guidelines need to be developed for appropriate roof rack structural loads and appropriate designs for different locations.

20. **Structural requirements for PV shingles.** Several sections on asphalt shingles cover the types and numbers of needed fasteners in typical and high wind areas, how the underlayment is applied, protection against ice buildup, and the proper installation of flashings. Identical requirements may apply to PV shingles. However, the different physical characteristics of PV and asphalt shingles may require changes in or additions to the requirements of IRC Section 905 when applied to PV shingles. This is an area of possible research for DOE or an interested standards or manufacturer's organization.
21. **Access and safety issues roof-top PV and SHW panels and other equipment.** The enforcement of access and safety codes as applied to PV systems could provide major economic and architectural obstacles to the widespread implementation of this technology. Permanent ladders, railings, access space between panels, and similar constraints could be imposed on roof-top mounted systems. It must be remembered that these requirements arose from real safety issues during the maintenance of mechanical systems. The problem for the PV industry is to include language in the codes that specifically exempt their systems from these requirements or to otherwise provide data that will convince local code officials that these requirements are unnecessary.
22. **Calculating proper roof dead loads for SHW systems.** Some designs of active SHW systems, such as those with a roof-located water storage tank, can produce highly concentrated roof loading. Higher weights are more likely to reach the roof dead-load limitations of 15 PSF (and 9 PSF in seismic areas). While calculation of the maximum weight of these systems is relatively easy to determine, the applicable area is not. The roof structure needs to be designed and built to prevent both general and local failure. Loads over small areas need to be solidly supported and the structure must transmit the resulting loads to its supporting structural elements. If active SHW systems are installed on existing or new buildings, the roof structure may need to be evaluated to determine if excessive loading is a problem. Guidelines for the proper approach to this issue may be an appropriate area for research.
23. **Determining appropriate solar heat gain coefficient limits for glazing in different orientations.** There are restrictions for the solar heat gain coefficient for areas with less than 3500 heating-degree-days. The area-weighted average solar heat gain coefficient for all glazing, including shading effects, must be less than 0.4. The purpose here is to decrease excessive heat gains to reduce cooling loads. However, the impacts on cooling loads are greater for south- or west-facing windows than for other orientations. Directional heat gain coefficient limits may be another area for DOE research.
24. **Guidelines to reduce overheating for designs with innovative glazing, shading, and other features.** In the prescriptive path, for locations with heating-degree days less than 3,500, the combined solar-heat-gain coefficient (the area weighted-average) of all glazed fenestration products (including the effects of any permanent exterior solar shading devices) in the building shall not exceed 0.4. The purpose here is to reduce heat gains during cooling periods. It is not clear how code officials might interpret this in regards to switchable glazing or other possible controllable glazing strategies. No consideration is given in the prescriptive path to other methods of

reducing excessive solar gains, including exterior or interior shading. The solar heat gain coefficients also do not consider the variations in solar climates found in different locations. The entire area of optimizing glazing and shading designs for passive solar performance and prevention of overheating could be a DOE research project. Guidelines for designs appropriate for different locations could be developed.

## 9.0 Appendix E

### Tables of Code References, Categorized by Renewable Energy and Energy Efficiency Technology

The following tables contain the references for each technology in the building codes reviewed for this report. A separate table is provided for each technology. These tables are not necessarily comprehensive.

**Table 3. Code References for Photovoltaic Systems in Buildings and Building-Integrated Photovoltaic Systems**

Code	Section	Reference No	Description
IECC	Materials and Equipment	103	Alternate materials and method of construction, design of insulating systems
IECC	Definitions	201	General definitions
IECC	Residential Building Systems Analysis	402.1	<i>Energy analysis</i>
IECC	Residential Building Systems Analysis	402.1.1	Standard design
IECC	Residential Building Systems Analysis	402.1.2	Proposed design
IECC	Residential Building Systems Analysis	403	Renewable energy source analysis
IECC	Residential Building Systems Analysis	403.1.1	Solar energy exclusion, one
IECC	Residential Building Systems Analysis	403.2	Documentation
IRC	Solar Systems	2701.2.2	Roof-mounted collectors
IRC	Building Planning	301.1	Design
IRC	Building Planning	301.2	Climatic and geography design criteria
IRC	Building Planning	301.2.1	Wind limitations
IRC	Building Planning	301.2.1.1	Design criteria for wind
IRC	Building Planning	301.2.2.2	Anchored stone and masonry veneer
IRC	Building Planning	301.2.2.4	Weight of materials

<b>Code</b>	<b>Section</b>	<b>Reference No</b>	<b>Description</b>
IRC	Building Planning	301.2.2.5	Height limitations
IRC	Building Planning	301.3	Dead load
IRC	Building Planning	308.3	Human impact loads for glazing units
IRC	Building Planning	308.4	Hazardous locations for glazing units
IRC	Building Planning	308.5	Wind, snow, and dead loads on glass
IRC	Building Planning	308.5.1	Vertical glass loads
IRC	Building Planning	308.5.2	Sloped glass loads
IRC	Building Planning	308.6.2	Skylight permitted materials
IRC	Building Planning	320.4	Penetrations between separate dwelling units
IRC	Energy Conservation	38	Energy conservation
IRC	Electrical	39	Reference to the 1998 International One- and Two-Family Dwelling Code
IRC	Wall Construction	610	Windows
IRC	Wall Covering	703.1	General exterior coverings
IRC	Wall Covering	703.2	Weather-resistant sheathing paper
IRC	Roof-Ceiling Construction	801.1	Application of roof-ceiling construction
IRC	Roof-Ceiling Construction	801.2	Requirements for roof-ceiling construction
IRC	Roof Assemblies and Rooftop Structures	902	Roof covering materials
IRC	Roof Assemblies and Rooftop Structures	904.3	Material specifications and physical characteristics
IRC	Roof Assemblies and Rooftop Structures	904.4	Product identification
IRC	Roof Assemblies and Rooftop Structures	905	Roof coverings with slopes 2:12 or greater
IRC	Roof Assemblies and Rooftop Structures	905.4	Metal roof panels
IRC	Roof Assemblies and Rooftop Structures	908.2	Rooftop structures: Towers, spires, dome and cupolas

<b>Code</b>	<b>Section</b>	<b>Reference No</b>	<b>Description</b>
NEC	Equipment for General Use	410-74	Direct-Current equipment
NEC	Equipment for General Use	411-2	Lighting systems operating at 30 volts or Less
NEC	Equipment for General Use	411-3	Lighting systems operating at 30 volts or less: listing requirement
NEC	Equipment for General Use	411-4	Lighting systems operating at 30 volts or less: locations not permitted
NEC	Equipment for General Use	411-7	Lighting systems operating at 30 volts or less: hazardous locations
NEC	Storage Batteries	480-8	Battery location
NEC	Storage Batteries	480-9	Battery vents
NEC	Interconnected Electric Power Production Sources	705	General
NEC	Interconnected Electric Power Production Sources	705.21	Disconnecting means, equipment
NEC	Interconnected Electric Power Production Sources	705.240	Loss of primary source
NEC	Circuits and Equipment Operating at Less Than 50 Volts	720	General
NEC 690		690-1	Scope
NEC 690		690-10	Stand-alone systems
NEC 690		690-13	Disconnecting means
NEC 690		690-18	Installation and service of an array
NEC 690		690-3	Other articles

<b>Code</b>	<b>Section</b>	<b>Reference No</b>	<b>Description</b>
NEC 690		690-31(b)	Wiring methods: single conductor cable
NEC 690		690-31(c)	Wiring methods: flexible cords and cables
NEC 690		690-31(d)	Wiring methods: small conductor cables
NEC 690		690-33	Connectors
NEC 690		690-4(a)	Installation of solar PV systems
NEC 690		690-4(b)	Conductors of different systems
NEC 690		690-4(c)	Module connection arrangement
NEC 690		690-4(d)	Equipment
NEC 690		690-41	Grounding
NEC 690		690-5	Ground fault protection
NEC 690		690-6	AC modules
NEC 690		690-7(a)	Maximum voltage
NEC 690		690-7(b)	Direct-Current utilization circuits
NEC 690		690-7(c)	Photovoltaic source and output circuits
NEC 690		690-7(d)	Circuits over 150 volts to ground
NEC 690		690-8	Circuit sizing and current
NEC 690		690-8(a)(1)	Computation of maximum PV source circuit current
NEC 690		690-8(a)(2)	Computation of maximum PV source output current
NEC 690		690-8(a)(3)	Inverter output circuit current

<b>Code</b>	<b>Section</b>	<b>Reference No</b>	<b>Description</b>
NEC 690		690-8(a)(4)	Stand-alone input circuit current
NEC 690		690-8(b)	Ampacity and overcurrent devices
NEC 690		690-8(c)	Systems with multiple DC voltages
NEC 690		690-9	Overcurrent protection
IMC	General Regulations	304.8	Guards
IMC	General Regulations	306.5	Equipment and appliances on roofs or elevated structures
IMC	General Regulations	306.6	Sloped roofs

**Table 4. Code References for Active Solar Domestic Hot Water and Space-Heating Systems**

<b>Code</b>	<b>Section</b>	<b>Reference No</b>	<b>Description</b>
IECC	Materials and Equipment	103	Alternate materials and method of construction, design of insulating systems
IECC	Definitions	201	General definitions
IECC	Residential Building Systems Analysis	402.1	Energy analysis
IECC	Residential Building Systems Analysis	402.1.1	Standard design
IECC	Residential Building Systems Analysis	402.1.2	Proposed design
IECC	Residential Building Systems Analysis	403	Renewable energy source analysis
IECC	Residential Building Systems Analysis	403.1.1	Solar energy exclusion, one
IECC	Residential Building Systems Analysis	403.2	Documentation
IECC	Residential / Component Performance Approach	504.2	Water heaters, storage tanks, and boilers
IECC	Residential / Component Performance Approach	504.2.2	Combination service water-heating/space-heating boilers
IMC	Administration	102.9	Requirements not covered by code
IMC	Solar Systems	15	Solar systems
IMC	Solar Systems	1502.1	Solar systems: access
IMC	Solar Systems	1502.3	Roof-mounted collectors

<b>Code</b>	<b>Section</b>	<b>Reference No</b>	<b>Description</b>
IMC	Solar Systems	1502.3.1	Collectors mounted above the roof
IMC	Solar Systems	1502.3.5	Filtering
IMC	General Regulations	301.12	Wind resistance
IMC	General Regulations	301.14	Seismic resistance
IMC	General Regulations	301.7	Electrical
IMC	General Regulations	302.1	Penetration of floor/ceiling assemblies and fire-resistance rated assemblies
IMC	General Regulations	303.4	Protection from damage
IMC	General Regulations	303.6	Outdoor locations
IMC	General Regulations	304.8	Guards
IMC	General Regulations	306.5	Equipment and appliances on roofs or elevated structures
IMC	General Regulations	306.6	Sloped roofs
IPC	Administration	105.4	Alternative engineered design
IPC	General Regulations	305.1	Corrosion
IPC	General Regulations	305.2	Breakage
IPC	General Regulations	305.3	Stress and strain
IPC	General Regulations	305.6	Freezing
IPC	General Regulations	308	Piping support
IPC	General Regulations	312.9	Inspection and testing of backflow prevention assemblies
IPC	Fixtures, Faucets and Fixture Fittings	424.4	Shower valves
IPC	Water Heaters	501.2	Water heater as space heater

<b>Code</b>	<b>Section</b>	<b>Reference No</b>	<b>Description</b>
IPC	Water Heaters	501.6	Water temperature control in piping from tankless heaters
IPC	Water Heaters	501.7	Pressure markings of storage tanks
IPC	Water Heaters	501.8	Temperature controls
IPC	Water Heaters	504.3	Energy cutoff device
IPC	Water Supply and Distribution	601.2	Solar energy utilization
IPC	Water Supply and Distribution	602.3.4	Disinfection of system
IPC	Water Supply and Distribution	605.1	Water compatibility
IPC	Water Supply and Distribution	605.21	Joints between different materials
IPC	Water Supply and Distribution	606.5.10	Pressure relief for tanks
IPC	Water Supply and Distribution	606.5.9	Pressure tanks, vacuum relief
IPC	Water Supply and Distribution	608.13	Backflow protection
IPC	Water Supply and Distribution	608.16.3	Heat exchangers
IPC	Water Supply and Distribution	610	Disinfection of potable water system
IRC	Heating and Cooling Equipment	1401.4	Sizing
IRC	Boilers/Water Heaters	2307	Water heaters
IRC	Solar Systems	2701.2.1	Access
IRC	Solar Systems	2701.2.2	Roof-mounted collectors
IRC	Solar Systems	2701.2.3	Pressure and temperature relief
IRC	Solar Systems	2701.2.4	Vacuum relief
IRC	Solar Systems	2701.2.5	Protection from freezing
IRC	Solar Systems	2701.2.6	Expansion tanks
IRC	Solar Systems	2701.2.7	Roof penetration
IRC	Solar Systems	2701.3.1	Labeling of collectors
IRC	Solar Systems	2701.3.2	Labeling of thermal storage units

<b>Code</b>	<b>Section</b>	<b>Reference No</b>	<b>Description</b>
IRC	Solar Systems	2701.4	Prohibited fluids
IRC	Solar Systems	2701.5	Backflow protection
IRC	Plumbing Administration	2903.6	Water-supply system testing
IRC	Building Planning	301.1	Design
IRC	Building Planning	301.2	Climatic and geography design criteria
IRC	Building Planning	301.2.1	Wind limitations
IRC	Building Planning	301.2.1.1	Design criteria for wind
IRC	Building Planning	301.2.2.2	Anchored stone and masonry veneer
IRC	Building Planning	301.2.2.4	Weight of materials
IRC	Building Planning	301.2.2.5	Height limitations
IRC	Building Planning	301.3	Dead load
IRC	Building Planning	308.3	Human impact loads for glazing units
IRC	Building Planning	308.4	Hazardous locations for glazing units
IRC	Building Planning	308.5	Wind, snow and dead loads on glass
IRC	Building Planning	308.5.1	Vertical glass loads
IRC	Building Planning	308.5.2	Sloped glass loads
IRC	General Plumbing Requirements	3101.1	Scope
IRC	General Plumbing Requirements	3105	Support
IRC	General Plumbing Requirements	3109.1	Materials evaluation and listing
IRC	General Plumbing Requirements	3109.2	Water-supply systems
IRC	Building Planning	317.1.1	Foam plastic surface burning characteristics
IRC	Building Planning	317.1.2	Thermal barrier of foam plastics
IRC	Building Planning	317.2.1	Masonry or concrete construction with foam plastic materials
IRC	Building Planning	317.2.2	Roofing with foam plastic materials
IRC	Building Planning	317.2.3	Attics with foam plastic materials

<b>Code</b>	<b>Section</b>	<b>Reference No</b>	<b>Description</b>
IRC	Building Planning	319.1	Insulation
IRC	Building Planning	320.4	Penetrations between separate dwelling units
IRC	Water Heaters	3301.1	Required water heaters
IRC	Water Heaters	3301.3	Location
IRC	Water Heaters	3301.5	Required pan
IRC	Water Heaters	3301.7	Energy cutoff device
IRC	Water Heaters	3302.1	Protection of potable water for water heaters used for space heating
IRC	Water Heaters	3302.2	Scald protection for water heaters used for space heating
IRC	Water Supply and Distribution	3401.1	Potable water required
IRC	Water Supply and Distribution	3402.1	Protection of potable water supply: connections
IRC	Water Supply and Distribution	3402.2.1	Air gaps
IRC	Water Supply and Distribution	3402.2.2	Atmospheric vacuum breakers
IRC	Water Supply and Distribution	3402.2.3	Backflow preventer with intermediate atmospheric vent
IRC	Water Supply and Distribution	3402.2.5	Pressure-type vacuum breakers
IRC	Water Supply and Distribution	3402.2.6	Reduced pressure principal backflow preventer
IRC	Water Supply and Distribution	3402.4.3	Solar systems
IRC	Water Supply and Distribution	3403.5	Determining water-supply fixture units
IRC	Water Supply and Distribution	3403.8	Size of water-service mains, branch mains and risers
IRC	Energy Conservation	38	Energy conservation
IRC	Building Planning	391.1 Exception 1	Insulation
IRC	Building Planning	391.1 Exception 2	Insulation

<b>Code</b>	<b>Section</b>	<b>Reference No</b>	<b>Description</b>
IRC	Roof-Ceiling Construction	801.2	Requirements for roof-ceiling construction
IRC	Roof Assemblies and Rooftop Structures	902	Roof covering materials
IRC	Roof Assemblies and Rooftop Structures	904.3	Material specifications and physical characteristics
IRC	Roof Assemblies and Rooftop Structures	904.4	Product identification
IRC	Roof Assemblies and Rooftop Structures	905	Roof coverings with slopes 2:12 or greater
IRC	Roof Assemblies and Rooftop Structures	905.4	Metal roof panels
IRC	Roof Assemblies and Rooftop Structures	908.2	Rooftop structures: Towers, spires, dome and cupolas

**Table 5. Code References for Active Solar Domestic Hot Water and Space-Heating Systems: Passive Solar**

<b>Code</b>	<b>Section</b>	<b>Reference No</b>	<b>Description</b>
IECC	Administration and Enforcement	Table 101.4.2.4	Prescriptive path for additions and window replacements
IECC	Administration and Enforcement	101.4.2	Application to existing buildings
IECC	Administration and Enforcement	101.4.2.4	Prescriptive path for additions and window replacements
IECC	Materials and Equipment	102.3	Fenestration product rating, certification, and labeling
IECC	Materials and Equipment	103	Alternate materials and method of construction, design of insulating systems
IECC	Definitions	201	General definitions
IECC	Definitions	201	General definitions
IECC	Design Conditions	302.1	Exterior design conditions
IECC	Residential Building Systems Analysis	402.1	Energy analysis
IECC	Residential Building Systems Analysis	402.1.1	Standard design
IECC	Residential Building Systems Analysis	402.1.2	Proposed design
IECC	Residential Building Systems Analysis	402.1.3.1.1	Orientation, standard-design glazing systems
IECC	Residential Building Systems Analysis	402.1.3.1.3	Exterior shading, standard design
IECC	Residential Building Systems Analysis	402.1.3.1.5	Interior shading, standard design and proposed design
IECC	Residential Building Systems Analysis	402.1.3.10	Air infiltration

<b>Code</b>	<b>Section</b>	<b>Reference No</b>	<b>Description</b>
IECC	Residential Building Systems Analysis	402.1.3.2	Passive solar
IECC	Residential Building Systems Analysis	402.1.3.3	Heat storage (thermal mass)
IECC	Residential Building Systems Analysis	403	Renewable energy source analysis
IECC	Residential Building Systems Analysis	403.1.2	Solar energy exclusion, two
IECC	Residential Building Systems Analysis	403.2	Documentation
IECC	Residential / Component Performance Approach	502.1.1	Thermal capacity
IECC	Residential / Component Performance Approach	503.3.1	Load calculations
IMC	Solar Systems	1502.1	Solar systems: access
IMC	Solar Systems	1502.2	Solar systems: controlling condensation
IMC	Solar Systems	1502.3.5	Filtering
IRC	Combustion Air	2001.1.1	Buildings of unusually tight construction
IRC	Building Planning	301.1	Design
IRC	Building Planning	301.2	Climatic and geography design criteria
IRC	Building Planning	301.2.1	Wind limitations
IRC	Building Planning	301.2.1.1	Design criteria for wind
IRC	Building Planning	301.2.2	Seismic limitations
IRC	Building Planning	301.2.2.2	Anchored stone and masonry veneer
IRC	Building Planning	301.2.2.4	Weight of materials
IRC	Building Planning	301.2.2.5	Height limitations
IRC	Building Planning	301.2.2.7	Concrete construction

<b>Code</b>	<b>Section</b>	<b>Reference No</b>	<b>Description</b>
IRC	Building Planning	301.3	Dead load
IRC	Building Planning	302.2	Openings
IRC	Building Planning	303.1	Habitable rooms
IRC	Building Planning	303.1.exception 1	303.1 Exception 1
IRC	Building Planning	303.1.exception 2	303.1 Exception 2
IRC	Building Planning	303.3	Bathrooms
IRC	Building Planning	303.6	Required heating
IRC	Building Planning	308.3	Human impact loads for glazing units
IRC	Building Planning	308.4	Hazardous locations for glazing units
IRC	Building Planning	308.5	Wind, snow and dead loads on glass
IRC	Building Planning	308.5.1	Vertical glass loads
IRC	Building Planning	308.5.2	Sloped glass loads
IRC	Building Planning	310.1	Emergency escape required
IRC	Building Planning	317.1.1	Foam plastic surface burning characteristics
IRC	Building Planning	317.1.2	Thermal barrier of foam plastics
IRC	Building Planning	317.2.1	Masonry or concrete construction with foam plastic materials
IRC	Building Planning	317.2.2	Roofing with foam plastic materials
IRC	Building Planning	317.2.3	Attics with foam plastic materials
IRC	Building Planning	319.1	Insulation
IRC	Building Planning	321.1	Moisture vapor retarder required
IRC	Energy Conservation	38	Energy conservation
IRC	Building Planning	391.1 Exception 1	Insulation
IRC	Building Planning	391.1 Exception 2	Insulation
IRC	Foundations	408.1	Crawl space ventilation
IRC	Wall Construction	602.3	Stud spacing
IRC	Wall Construction	602.8	Fireblocking required
IRC	Wall Construction	603	Steel wall framing

<b>Code</b>	<b>Section</b>	<b>Reference No</b>	<b>Description</b>
IRC	Wall Construction	604	General masonry construction
IRC	Wall Construction	608	Insulating concrete form wall construction
IRC	Wall Construction	609	Grouted masonry
IRC	Wall Construction	610	Windows
IRC	Wall Construction	611	Sliding glass doors
IRC	Wall Covering	702.5	Other finishes for interior wall covering
IRC	Wall Covering	703.7.1	Interior masonry veneer support
IRC	Roof-Ceiling Construction	804.3.3	Allowable rafter spans for roof-ceiling construction
IRC	Roof-Ceiling Construction	806.1	Ventilation required for roofs
IRC	Roof Assemblies and Rooftop Structures	908.2	Rooftop structures: towers, spires, dome, and cupolas

**Table 6. Code References for Passive Solar:  
Innovative Envelope and Foundation Systems**

<b>Code</b>	<b>Section</b>	<b>Reference No</b>	<b>Description</b>
IECC	Administration and Enforcement	Table 101.4.2.4	Prescriptive path for additions and window replacements
IECC	Administration and Enforcement	101.4.2	Application to existing buildings
IECC	Administration and Enforcement	101.4.2.4	Prescriptive path for additions and window replacements
IECC	Materials and Equipment	102.3	Fenestration product rating, certification, and labeling
IECC	Materials and Equipment	103	Alternate materials and method of construction, design of insulating systems
IECC	Definitions	201	General definitions
IECC	Definitions	201	General definitions
IECC	Definitions	201	General definitions
IECC	Definitions	201	General definitions
IECC	Design Conditions	302.1	Exterior design conditions
IECC	Residential Building Systems Analysis	402.1	Energy analysis
IECC	Residential Building Systems Analysis	402.1.1	Standard design
IECC	Residential Building Systems Analysis	402.1.2	Proposed design
IECC	Residential Building Systems Analysis	402.1.3.1.1	Orientation, standard-design glazing systems
IECC	Residential Building Systems Analysis	402.1.3.1.3	Exterior shading, standard design
IECC	Residential Building Systems Analysis	402.1.3.1.5	Interior shading, standard design, and proposed design
IECC	Residential Building Systems Analysis	402.1.3.10	Air infiltration

<b>Code</b>	<b>Section</b>	<b>Reference No</b>	<b>Description</b>
IECC	Residential Building Systems Analysis	402.1.3.3	Heat storage (thermal mass)
IECC	Residential Building Systems Analysis	402.1.3.4	Building thermal envelope-surface areas and volume
IECC	Residential Building Systems Analysis	402.2.2	Equivalent energy units
IECC	Residential / Component Performance Approach	502.1.1	Thermal capacity
IECC	Residential / Component Performance Approach	502.1.4	Recessed lighting fixtures
IECC	Residential / Component Performance Approach	502.2	Heating and cooling criteria
IECC	Residential / Component Performance Approach	502.2.2	Compliance by total building envelope performance
IECC	Residential / Component Performance Approach	502.2.3	Compliance by acceptable practice on an individual component basis
IECC	Residential / Component Performance Approach	502.2.3.1	Walls
IECC	Residential / Component Performance Approach	502.2.3.2	Roof/ceiling
IECC	Residential / Component Performance Approach	502.2.3.3	Floors over unheated spaces

<b>Code</b>	<b>Section</b>	<b>Reference No</b>	<b>Description</b>
IECC	Residential / Component Performance Approach	502.2.3.4	Slab on grade floors
IECC	Residential / Component Performance Approach	502.2.3.5	Crawl space walls
IECC	Residential / Component Performance Approach	502.2.3.6	Basement walls
IECC	Residential / Component Performance Approach	502.2.4	Compliance by prescriptive specification on an individual component basis
IECC	Residential / Component Performance Approach	502.2.4.13	Tables not applicable
IECC	Residential / Component Performance Approach	502.2.4.14	Climates greater than 13,000 HDD
IECC	Residential / Component Performance Approach	502.3.1	Air leakage for window and door assemblies
IFGC	General Regulations	304.1	Combustion, ventilation, and dilution air: general
IMC	Refrigeration	1102	System requirements
IMC	Ventilation	402.2	Natural ventilation: ventilation area required
IMC	Ventilation	404	Ventilation of uninhabited spaces
IMC	Combustion Air	701.2	Combustion and dilution air required
IMC	Combustion Air	702.1	Inside air: air from the same room or space
IMC	Combustion Air	703.1.2	Outdoor air: size of direct openings
IMC	Combustion Air	703.1.3	Outdoor air: size of horizontal openings
IMC	Combustion Air	704.1.2	Outdoor air: size and configuration of the opening

<b>Code</b>	<b>Section</b>	<b>Reference No</b>	<b>Description</b>
IPC	General Regulations	305.1	Corrosion
IPC	General Regulations	305.2	Breakage
IPC	General Regulations	305.3	Stress and strain
IPC	General Regulations	305.6	Freezing
IPC	General Regulations	308	Piping support
IRC	Roof Assemblies and Rooftop Structures	1006	Exterior air for fireplaces
IRC	Exhaust Systems	1801	Clothes dryer exhaust
IRC	Combustion Air	2001.1.1	Buildings of unusually tight construction
IRC	Combustion Air	2003	All air from outdoors
IRC	Title, Purpose and Scope	202	Definitions for story height, story above grade
IRC	Title, Purpose and Scope	202	Definitions for vapor barrier
IRC	Specific Gas Fueled Appliances	28-608	Clothes dryer exhaust
IRC	Building Planning	301.1	Design
IRC	Building Planning	301.2	Climatic and geography design criteria
IRC	Building Planning	301.2.1	Wind limitations
IRC	Building Planning	301.2.1.1	Design criteria for wind
IRC	Building Planning	301.2.2	Seismic limitations
IRC	Building Planning	301.2.2.2	Anchored stone and masonry veneer
IRC	Building Planning	301.2.2.4	Weight of materials
IRC	Building Planning	301.2.2.5	Height limitations
IRC	Building Planning	301.2.2.7	Concrete construction
IRC	Building Planning	301.3	Dead load
IRC	Building Planning	303.1	Habitable rooms
IRC	Building Planning	303.1 exception 1	303.1 Exception 1

<b>Code</b>	<b>Section</b>	<b>Reference No</b>	<b>Description</b>
IRC	Building Planning	303.1 Exception 2	303.1 Exception 2
IRC	Building Planning	303.3	Bathrooms
IRC	Building Planning	303.6	Required heating
IRC	Building Planning	308.5	Wind, snow and dead loads on glass
IRC	Building Planning	308.5.1	Vertical glass loads
IRC	Building Planning	308.5.2	Sloped glass loads
IRC	Building Planning	310.1	Emergency escape required
IRC	Building Planning	317.1.1	Foam plastic surface burning characteristics
IRC	Building Planning	317.1.2	Thermal barrier of foam plastics
IRC	Building Planning	317.2.1	Masonry or concrete construction with foam plastic materials
IRC	Building Planning	317.2.2	Roofing with foam plastic materials
IRC	Building Planning	317.2.3	Attics with foam plastic materials
IRC	Building Planning	318.1	Wall and ceiling flame spread and smoke density
IRC	Building Planning	319.1	Insulation
IRC	Building Planning	321.1	Moisture vapor retarder required
IRC	Building Planning	323.4	Foam plastic protection against termites
IRC	Energy Conservation	38	Energy conservation
IRC	Building Planning	391.1 Exception 1	Insulation
IRC	Building Planning	391.1 Exception 2	Insulation
IRC	Foundations	403.3	Insulated footings
IRC	Foundations	403.3.1	Protection of horizontal insulation below ground
IRC	Foundations	404.4	Insulating concrete form foundation walls
IRC	Foundations	404.4.1	Applicability of Insulating concrete form foundation walls
IRC	Foundations	408.1	Crawl space ventilation
IRC	Wall Construction	602.3	Stud spacing
IRC	Wall Construction	602.8	Fireblocking required
IRC	Wall Construction	603	Steel wall framing

<b>Code</b>	<b>Section</b>	<b>Reference No</b>	<b>Description</b>
IRC	Wall Construction	604	General masonry construction
IRC	Wall Construction	608	Insulating concrete form wall construction
IRC	Wall Construction	609	Grouted masonry
IRC	Wall Construction	610	Windows
IRC	Wall Construction	611	Sliding glass doors
IRC	Wall Covering	702.5	Other finishes for interior wall covering
IRC	Wall Covering	703.1	General exterior coverings
IRC	Wall Covering	703.2	Weather-resistant sheathing paper
IRC	Wall Covering	703.7.1	Interior masonry veneer support
IRC	Roof-Ceiling Construction	801.1	Application of roof-ceiling construction
IRC	Roof-Ceiling Construction	804.3.3	Allowable rafter spans for roof-ceiling construction
IRC	Roof-Ceiling Construction	806.1	Ventilation required for roofs
IRC	Roof-Ceiling Construction	808	Combustible insulation clearance
IRC	Roof Assemblies and Rooftop Structures	908.2	Rooftop structures: towers, spires, dome and cupolas

**Table 7. Code References for Envelope and Fenestration Systems:  
Innovative Heating, Ventilation, and Air Conditioning (HVAC) Systems**

<b>Code</b>	<b>Section</b>	<b>Reference No</b>	<b>Description</b>
IECC	Materials and Equipment	103	Alternate materials and method of construction, design of insulating systems
IECC	Definitions	201	General definitions
IECC	Definitions	201	General definitions
IECC	Definitions	201	General definitions
IECC	Residential Building Systems Analysis	402.1	Energy analysis
IECC	Residential Building Systems Analysis	402.1.1	Standard design
IECC	Residential Building Systems Analysis	402.1.2	Proposed design
IECC	Residential Building Systems Analysis	402.1.3.10	Air infiltration
IECC	Residential Building Systems Analysis	402.1.3.5	Heating and cooling controls
IECC	Residential Building Systems Analysis	402.1.3.7	Domestic hot water
IECC	Residential Building Systems Analysis	402.2.2	Equivalent energy units
IECC	Residential / Component Performance Approach	503.1	Mechanical systems: general
IECC	Residential / Component Performance Approach	503.3.6	Transport energy
IECC	Residential / Component Performance Approach	504.2	Water heaters, storage tanks and boilers

<b>Code</b>	<b>Section</b>	<b>Reference No</b>	<b>Description</b>
IECC	Residential / Component Performance Approach	504.2.2	Combination service water-heating/space-heating boilers
IFGC	Administration	105.2	Alternative materials, methods and equipment
IFGC	Administration	105.3	Required testing
IFGC	Administration	105.4	Material and equipment reuse
IFGC	General Regulations	301.10	Wind resistance
IFGC	General Regulations	301.12	Seismic resistance
IFGC	General Regulations	301.2	Energy utilization
IFGC	General Regulations	301.3	Installation of listed and unlisted appliances
IFGC	General Regulations	301.6	Plumbing connections
IFGC	General Regulations	304.1	Combustion, ventilation and dilution air: general
IFGC	Specific Appliances	615	Engine and gas turbine powered equipment
IFGC	Specific Appliances	626.10	Cooling units used with heating boilers
IFGC	Specific Appliances	626.11	Cooling units used with heating boilers
IFGC	Specific Appliances	626.2	Air-conditioning equipment: independent gas piping
IFGC	Specific Appliances	626.3	Air-conditioning equipment: connection of gas engine-powered air conditioners
IFGC	Specific Appliances	626.6	Unlisted equipment clearance
IFGC	Specific Appliances	626.9	Refrigeration coils
IFGC	Specific Appliances	629	Infrared radiant heaters
IFGC	Specific Appliances	630	Listed boilers

<b>Code</b>	<b>Section</b>	<b>Reference No</b>	<b>Description</b>
IFGC	Specific Appliances	631	Unlisted boilers
IFGC	Specific Appliances	633	Clearances to combustibile materials
IMC	Administration	102.9	Requirements not covered by code
IMC	Refrigeration	1102	System requirements
IMC	General Regulations	301.12	Wind resistance
IMC	General Regulations	301.14	Seismic resistance
IMC	General Regulations	301.7	Electrical
IMC	General Regulations	302.1	Penetration of floor/ceiling assemblies and fire-resistance rated assemblies
IMC	General Regulations	303.4	Protection from damage
IMC	General Regulations	303.6	Outdoor locations
IMC	General Regulations	304.8	Guards
IMC	General Regulations	306.5	Equipment and appliances on roofs or elevated structures
IMC	General Regulations	306.6	Sloped roofs
IMC	General Regulations	307.2	Evaporators and cooling coils
IMC	Ventilation	401.5	Opening location
IMC	Ventilation	403.2, 403.3	Mechanical ventilation: Outdoor air required
IMC	Ventilation	403.3.1	System operation
IMC	Ventilation	403.3.3	Variable air volume systems
IMC	Combustion Air	701.2	Combustion and dilution air required
IMC	Combustion Air	702.1	Inside Air: Air from the same room or space
IMC	Combustion Air	703.1.2	Outdoor Air: Size of direct openings
IMC	Combustion Air	703.1.3	Outdoor Air: Size of horizontal openings

<b>Code</b>	<b>Section</b>	<b>Reference No</b>	<b>Description</b>
IMC	Combustion Air	704.1.2	Outdoor air: size and configuration of the opening
IMC	Combustion Air	707.1	Forced-combustion air supply
IMC	Specific Appliances, etc.	904	Pellet fuel-burning appliances
IMC	Specific Appliances, etc.	905	Fireplace stoves and room heaters
IMC	Specific Appliances, etc.	920	Engine and gas turbine powered equipment and appliances
IPC	Administration	105.4	Alternative engineered design
IPC	Water Heaters	501.2	Water heater as space heater
IPC	Water Supply and Distribution	608.9	Reutilization prohibited
IRC	Roof Assemblies and Rooftop Structures	1006	Exterior air for fireplaces
IRC	Roof Assemblies and Rooftop Structures	1302.1	Approval for appliances
IRC	Roof Assemblies and Rooftop Structures	1303.1	Labeling of equipment
IRC	Roof Assemblies and Rooftop Structures	1305.1	Appliance access for inspection, service, repair and replacement
IRC	Heating and Cooling Equipment	1401.4	Sizing
IRC	Heating and Cooling Equipment	1403	Heat pump equipment
IRC	Exhaust Systems	1801	Clothes dryer exhaust
IRC	Duct Systems	19	Duct systems
IRC	Duct Systems	1901.3	Duct insulation
IRC	Duct Systems	1901.4	Under-floor plenums
IRC	Combustion Air	2001.1.1	Buildings of unusually tight construction

<b>Code</b>	<b>Section</b>	<b>Reference No</b>	<b>Description</b>
IRC	Combustion Air	2001.1.1	Buildings of unusually tight construction
IRC	Combustion Air	2003	All air from outdoors
IRC	Boilers/Water Heaters	2307	Water heaters
IRC	Refrigeration	2401.4	Insulation of refrigerant piping
IRC	Hydronic Piping	25	Hydronic piping
IRC	Gas Piping Installations	28-403.2.6.4	Corrugated stainless-steel tubing
IRC	Specific Gas Fueled Appliances	28-608	Clothes dryer exhaust
IRC	Building Planning	301.2	Climatic and geography design criteria
IRC	Energy Conservation	38	Energy conservation
IRC	Energy Conservation	38	Energy conservation (continued)
IRC	Energy Conservation	38	Reference to ICC International Energy Conservation Code
NEC	Fixed Electric Space-Heating Equipment	424	General
NEC	Motors, Motor Circuits and Controllers	430	General
NEC	Air Conditioning And Refrigerating Equipment	440	General
NEC	Circuits and Equipment Operating at Less Than 50 Volts	720	General
NEC	Class 1, Class 2, and Class 3 Remote-Control, Signaling, and Power-Limited Circuits	725	General

**Table 8. Code References for Innovative HVAC Systems:  
Electrical Lighting, Daylighting, and Associated Controls**

<b>Code</b>	<b>Section</b>	<b>Reference No</b>	<b>Description</b>
IECC	Materials and Equipment	102.3	Fenestration product rating, certification, and labeling
IECC	Materials and Equipment	103	Alternate materials and method of construction, design of insulating systems
IECC	Definitions	201	General definitions
IECC	Residential Building Systems Analysis	402.1	Energy analysis
IECC	Residential Building Systems Analysis	402.1.1	Standard design
IECC	Residential Building Systems Analysis	402.1.2	Proposed design
IECC	Residential Building Systems Analysis	402.1.3.1.1	Orientation, standard design glazing systems
IECC	Residential Building Systems Analysis	402.1.3.6	Internal heat gains
IECC	Residential Building Systems Analysis	402.2.2	Equivalent energy units
IECC	Residential Building Systems Analysis	403.2	Documentation
IECC	Residential / Component Performance Approach	502.1.4	Recessed lighting fixtures
IECC	Residential / Component Performance Approach	505.2	Lighting power budget
IRC	Building Planning	301.1	Design
IRC	Building Planning	301.2	Climatic and geography design criteria
IRC	Building Planning	301.2.1	Wind limitations

<b>Code</b>	<b>Section</b>	<b>Reference No</b>	<b>Description</b>
IRC	Building Planning	301.2.1.1	Design criteria for wind
IRC	Building Planning	301.2.2.2	Anchored stone and masonry veneer
IRC	Building Planning	301.2.2.4	Weight of materials
IRC	Building Planning	301.2.2.5	Height limitations
IRC	Building Planning	301.3	Dead load
IRC	Building Planning	302.2	Openings
IRC	Building Planning	308.5	Wind, snow, and dead loads on glass
IRC	Building Planning	308.5.1	Vertical glass loads
IRC	Building Planning	308.5.2	Sloped glass loads
IRC	Building Planning	310.1	Emergency escape required
IRC	Building Planning	317.1.1	Foam plastic surface burning characteristics
IRC	Building Planning	317.1.2	Thermal barrier of foam plastics
IRC	Building Planning	317.2.1	Masonry or concrete construction with foam plastic materials
IRC	Building Planning	317.2.2	Roofing with foam plastic materials
IRC	Building Planning	317.2.3	Attics with foam plastic materials
IRC	Building Planning	319.1	Insulation
IRC	Energy Conservation	38	Energy conservation
IRC	Building Planning	391.1 Exception 1	Insulation
IRC	Building Planning	391.1 Exception 2	Insulation
IRC	Roof-Ceiling Construction	801.2	Requirements for roof-ceiling construction
IRC	Roof Assemblies and Rooftop Structures	902	Roof covering materials
IRC	Roof Assemblies and Rooftop Structures	908.2	Rooftop structures: towers, spires, dome, and cupolas
NEC	Equipment for General Use	410-74	Direct-Current equipment

<b>Code</b>	<b>Section</b>	<b>Reference No</b>	<b>Description</b>
NEC	Equipment for General Use	410-80(b)	Dwelling occupancies
NEC	Equipment for General Use	410-81(b)	Lighting control within sight or locked type
NEC	Equipment for General Use	411-2	Lighting systems operating at 30 volts or less
NEC	Equipment for General Use	411-3	Lighting systems operating at 30 volts or less: listing requirement
NEC	Equipment for General Use	411-4	Lighting systems operating at 30 volts or less: locations not permitted
NEC	Equipment for General Use	411-7	Lighting systems operating at 30 volts or less: hazardous locations
NEC	Circuits and Equipment Operating at Less Than 50 Volts	720	General
NEC	Class 1, Class 2, and Class 3 Remote-Control, Signaling, and Power-Limited Circuits	725	General

**Table 9. Code References for Electrical Lighting, Daylighting, and Associated Controls: Innovative Thermal Storage Systems**

<b>Code</b>	<b>Section</b>	<b>Reference No</b>	<b>Description</b>
IECC	Materials and Equipment	103	Alternate materials and method of construction, design of insulating systems
IECC	Definitions	201	General definitions
IECC	Residential Building Systems Analysis	402.1	Energy analysis
IECC	Residential Building Systems Analysis	402.1.1	Standard design
IECC	Residential Building Systems Analysis	402.1.2	Proposed design
IECC	Residential / Component Performance Approach	503.1	Mechanical systems: general
IMC	Administration	102.9	Requirements not covered by code
IMC	General Regulations	301.12	Wind resistance
IMC	General Regulations	301.14	Seismic resistance
IMC	General Regulations	301.7	Electrical
IMC	General Regulations	303.6	Outdoor locations
IPC	Administration	105.4	Alternative-engineered design
IPC	General Regulations	305.1	Corrosion
IPC	General Regulations	305.2	Breakage
IPC	General Regulations	305.3	Stress and strain
IPC	General Regulations	305.6	Freezing

<b>Code</b>	<b>Section</b>	<b>Reference No</b>	<b>Description</b>
IPC	General Regulations	308	Piping support
IPC	General Regulations	312.9	Inspection and testing of backflow prevention assemblies
IPC	Fixtures, Faucets and Fixture Fittings	424.4	Shower valves
IPC	Water Heaters	501.2	Water heater as space heater
IPC	Water Heaters	501.7	Pressure markings of storage tanks
IPC	Water Heaters	501.8	Temperature controls
IPC	Water Heaters	504.3	Energy cutoff device
IPC	Water Supply and Distribution	608.13	Backflow protection
IRC	Roof Assemblies and Rooftop Structures	1302.1	Approval for appliances
IRC	Roof Assemblies and Rooftop Structures	1303.1	Labeling of equipment
IRC	Roof Assemblies and Rooftop Structures	1305.1	Appliance access for inspection, service, repair and replacement
IRC	Heating and Cooling Equipment	1401.4	Sizing
IRC	Building Planning	301.2	Climatic and geography design criteria
IRC	General Plumbing Requirements	3109.1	Materials evaluation and listing
IRC	General Plumbing Requirements	3109.2	Water-supply systems
IRC	Water Heaters	3301.1	Required water heaters
IRC	Water Heaters	3301.3	Location
IRC	Water Heaters	3301.5	Required pan
IRC	Water Heaters	3301.7	Energy cutoff device

<b>Code</b>	<b>Section</b>	<b>Reference No</b>	<b>Description</b>
IRC	Water Heaters	3302.1	Protection of potable water for water heaters used for space heating
IRC	Water Heaters	3302.2	Scald protection for water heaters used for space heating
IRC	Water Supply and Distribution	3401.1	Potable water required
IRC	Water Supply and Distribution	3402.1	Protection of potable water supply: connections
IRC	Water Supply and Distribution	3402.2.1	Air gaps
IRC	Water Supply and Distribution	3402.2.2	Atmospheric vacuum breakers
IRC	Water Supply and Distribution	3402.2.3	Backflow preventer with intermediate atmospheric vent
IRC	Water Supply and Distribution	3402.2.5	Pressure-type vacuum breakers
IRC	Water Supply and Distribution	3402.2.6	Reduced pressure principal backflow preventer
IRC	Water Supply and Distribution	3402.4.3	Solar systems
IRC	Water Supply and Distribution	3403.5	Determining water-supply fixture units
IRC	Water Supply and Distribution	3403.8	Size of water-service mains, branch mains, and risers
IRC	Energy Conservation	38	Energy conservation
IPC	Water Supply and Distribution	608.16.3	Heat exchangers

**Table 10. Code References for Innovative Thermal Storage Systems:  
Buildings Requiring No Heating/Cooling Equipment**

<b>Code</b>	<b>Section</b>	<b>Reference No</b>	<b>Description</b>
IECC	Materials and Equipment	103	Alternate materials and method of construction, design of insulating systems
IECC	Design Conditions	302.1	Exterior design conditions
IECC	Residential / Component Performance Approach	503.1	Mechanical systems: general
IECC	Residential / Component Performance Approach	503.3.1	Load calculations
IMC	Administration	102.9	Requirements not covered by code
IMC	General Regulations	301.7	Electrical
IRC	Heating and Cooling Equipment	1401.4	Sizing
IRC	Building Planning	301.2	Climatic and geography design criteria
IRC	Building Planning	303.6	Required heating
IRC	Energy Conservation	38	Energy conservation

**Table 11. Code References for Buildings Requiring No Heating and/or Cooling Equipment: Buildings Requiring No Conventional Air Distribution (Duct) Systems**

<b>Code</b>	<b>Section</b>	<b>Reference No</b>	<b>Description</b>
IECC	Materials and Equipment	103	Alternate materials and method of construction, design of insulating systems
IECC	Residential / Component Performance Approach	503.1	Mechanical systems: general
IMC	Administration	102.9	Requirements not covered by code
IMC	General Regulations	301.7	Electrical
IMC	Ventilation	403.2, 403.3	Mechanical ventilation: outdoor air required
IMC	Ventilation	403.3.1	System operation
IMC	Duct Systems	601	Scope
IMC	Specific Appliances, etc.	923.2	Forced-air warm-air furnaces: minimum duct sizes
IMC	Specific Appliances, etc.	923.3	Forced-air warm-air furnaces: heat pumps
IRC	Energy Conservation	38	Energy conservation

**Table 12. Code References for Buildings Requiring No  
Conventional Air-Distribution Systems: Solar-Assisted Ventilation Systems**

<b>Code</b>	<b>Section</b>	<b>Reference No</b>	<b>Description</b>
IECC	Residential Building Systems Analysis	402.1	Energy analysis
IECC	Residential Building Systems Analysis	402.1.1	Standard design
IECC	Residential Building Systems Analysis	402.1.2	Proposed design
IECC	Materials and Equipment	103	Alternate materials and method of construction, design of insulating systems
IECC	Residential / Component Performance Approach	503.1	Mechanical systems: general
IMC	Administration	102.9	Requirements not covered by code
IMC	General Regulations	302.1	Penetration of floor/ceiling assemblies and fire-resistance rated assemblies
IMC	General Regulations	303.6	Outdoor locations
IMC	Ventilation	403.2, 403.3	Mechanical ventilation: outdoor air required
IMC	Ventilation	403.3.1	System operation
IRC	Building Planning	301.1	Design
IRC	Building Planning	301.2	Climatic and geography design criteria
IRC	Energy Conservation	38	Energy conservation

**Table 13. Code References for Solar-Assisted Ventilation  
Systems: Desiccant Dehumidification Systems**

<b>Code</b>	<b>Section</b>	<b>Reference No</b>	<b>Description</b>
IECC	Materials and Equipment	103	Alternate materials and method of construction, design of insulating systems
IECC	Residential / Component Performance Approach	503.1	Mechanical systems: general
IFGC	General Regulations	301.2	Energy utilization
IFGC	General Regulations	301.3	Installation of listed and unlisted appliances
IMC	Administration	102.9	Requirements not covered by code

## 10. Appendix F

### References

1. International Code Council, Inc. April 1998. *International Residential Code for One- and Two-Family Dwellings, First Draft*. International Code Council, Inc. Falls Church, VA.
2. International Code Council, Inc. March 1998. *International Energy Conservation Code, 1998*. International Code Council, Inc. Falls Church, VA.
3. International Code Council, Inc. January 1998. *International Mechanical Code, 1998*. International Code Council, Inc. Falls Church, VA.
4. International Code Council, Inc. April 1998. *International Plumbing Code, 1997*. International Code Council, Inc. Falls Church, VA.
5. International Code Council, Inc. November 1997. *International Fuel Gas Code, 1997*. International Code Council, Inc. Falls Church, VA.
6. National Fire Protection Association. 1995. *National Electrical Code*. National Fire Protection Association. Quincy, MA.
7. National Fire Protection Association. 1999. Unpublished draft of Article 690 of the National Electrical Code, 1999: Solar Photovoltaic Systems. National Fire Protection Association. Quincy, MA.
8. Solar Rating and Certification Corporation. April 1997. *SRCC Document OG-300: Operating Guidelines and Minimum Standards for Certifying Solar Water Heating Systems: An Optional Solar Water Heating System Certification and Rating Program*. Solar Rating and Certification Corporation. Cocoa, FL.
9. American Society of Heating, Refrigerating and Air-Conditioning Engineers. 1993. *ASHRAE Standard 90.2-1993: Energy Efficient Design of New Low-Rise Residential Buildings*. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Atlanta, GA.
10. Balcomb, J. D. (2001). Mastering ENERGY-10: A User Manual for Version 1.3. 277 pp.; NREL Report No. BK-550-29780
11. Marion, W. and K. Urban. 1995. *User's Manual for TMY2s (Typical Meteorological Years) derived from the 1961-1990 National Solar Radiation Database*. NREL/TP-463-7668, National Renewable Energy Laboratory, Golden, CO.
12. Wiles, John. 1996. *Photovoltaic Power Systems and The National Electrical Code: Suggested Practices*. SAND96-2797. Sandia National Laboratories, Albuquerque, NM.
13. Klein, S., and Beckman, W. 1994. *TRNSYS: A transient simulation program*. *Engineering Experiment Station Report 38-14*. University of Wisconsin, Madison, WI.
14. Beckman, W. and Duffie, J. 1977. *Solar heating design by the f-Chart method*, John Wiley & Sons, New York, NY.
15. Lawrence Berkeley Laboratory. 1982. *DOE2 Engineers Manual*. Lawrence Berkeley Laboratory Report LBL-11353. National Technical Information Services, Springfield, VA.
16. Winkelmann, F.C.; Birdsall, B.E.; Buhl, W.F.; Ellington, K.L.; Erdem, A.E. 1993. *DOE-2 BDL Summary*. Lawrence Berkeley Laboratory Report LBL--34946, Berkeley, Calif.

**REPORT DOCUMENTATION PAGE***Form Approved*  
*OMB No. 0704-0188*

The public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing the burden, to Department of Defense, Executive Services and Communications Directorate (0704-0188). Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

**PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ORGANIZATION.**

<b>1. REPORT DATE (DD-MM-YYYY)</b> February 2005			<b>2. REPORT TYPE</b> Subcontractor Report		<b>3. DATES COVERED (From - To)</b> June 15, 1998, - September 15, 1998	
<b>4. TITLE AND SUBTITLE</b> Renewable Energy and Energy Efficiency Technologies in Residential Building Codes					<b>5a. CONTRACT NUMBER</b> DE-AC36-99-GO10337	
					<b>5b. GRANT NUMBER</b>	
					<b>5c. PROGRAM ELEMENT NUMBER</b>	
<b>6. AUTHOR(S)</b> D. Wortman and L. Echo-Hawk					<b>5d. PROJECT NUMBER</b> NREL/SR-550-32688	
					<b>5e. TASK NUMBER</b> SH04.6001	
					<b>5f. WORK UNIT NUMBER</b>	
<b>7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)</b> David Wortman, P.E., and Linda Echo-Hawk Wortman Engineering Boulder, Colorado					<b>8. PERFORMING ORGANIZATION REPORT NUMBER</b> AAA-8-18450-01	
<b>9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)</b> National Renewable Energy Laboratory 1617 Cole Blvd. Golden, CO 80401-3393					<b>10. SPONSOR/MONITOR'S ACRONYM(S)</b> NREL	
					<b>11. SPONSORING/MONITORING AGENCY REPORT NUMBER</b> NREL/SR-550-32688	
<b>12. DISTRIBUTION AVAILABILITY STATEMENT</b> National Technical Information Service U.S. Department of Commerce 5285 Port Royal Road Springfield, VA 22161						
<b>13. SUPPLEMENTARY NOTES</b> NREL Technical Monitor: S. Hayter						
<b>14. ABSTRACT (Maximum 200 Words)</b> This report is an attempt to describe the building code requirements and impediments to the application of EE and RE technologies in residential buildings. Several modern model building codes were reviewed. These are representative of the codes that will be adopted by most locations in the coming years. The codes reviewed for this report include: International Residential Code, First Draft, April 1998; International Energy Conservation Code, 1998; International Mechanical Code, 1998; International Plumbing Code, 1997; International Fuel Gas Code, 1997; National Electrical Code, 1996. These codes were reviewed as to their application to (1) PV systems in buildings and building-integrated PV systems and (2) active solar domestic hot water and space-heating systems. A discussion of general code issues that impact these technologies is also included. Examples of this are solar access and sustainability.						
<b>15. SUBJECT TERMS</b> model building codes; energy efficient; renewable energy; residential buildings; U.S. Department of Energy						
<b>16. SECURITY CLASSIFICATION OF:</b>			<b>17. LIMITATION OF ABSTRACT</b> UL	<b>18. NUMBER OF PAGES</b>	<b>19a. NAME OF RESPONSIBLE PERSON</b>	
<b>a. REPORT</b> Unclassified	<b>b. ABSTRACT</b> Unclassified	<b>c. THIS PAGE</b> Unclassified			<b>19b. TELEPHONE NUMBER (Include area code)</b>	

Standard Form 298 (Rev. 8/98)  
Prescribed by ANSI Std. Z39.18